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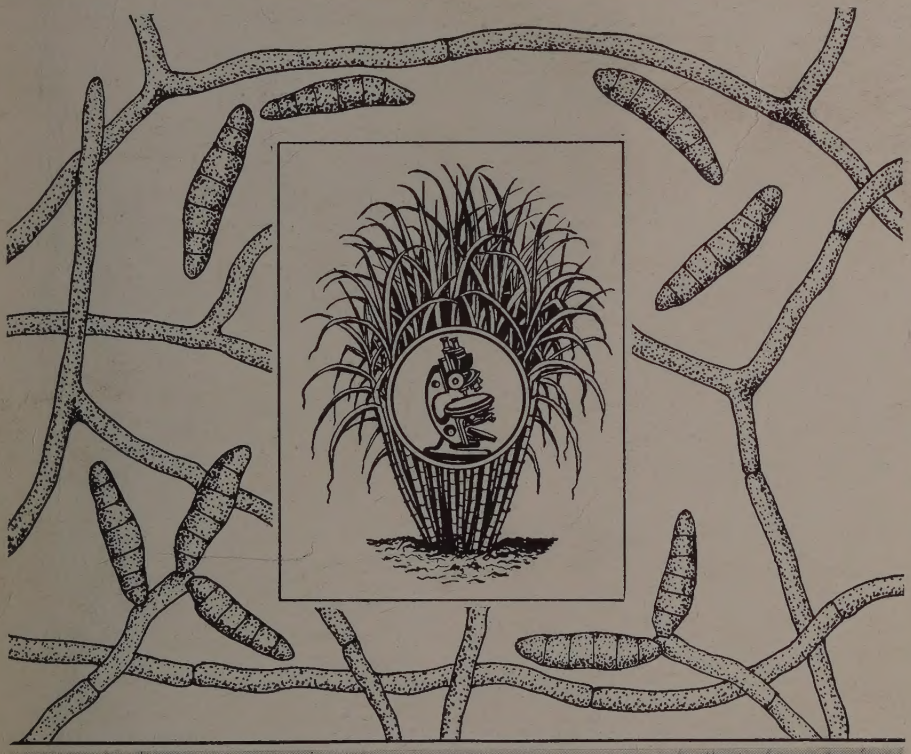

Eye spot disease, as well as other sugar-cane diseases in Hawaii, has caused serious reductions in sugar yields and has been most effectively controlled by planting resistant varieties. The variety on the left (Ewa 199) was killed by eye spot while the highly resistant variety (Ewa 533) on the right was not affected.

THIRD AND FOURTH QUARTERS, 194

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The Control of the Grass Armyworm, Laphygma exempta (Walker), in Hawaii by Parasites

By C. E. Pemberton

In view of the elaborate complex of beneficial insects operating in Hawaiian cane fields in the control of the common armyworm, Laphygma exempta, *the present paper has been prepared to emphasize the practical importance of the 15 species comprising the group and to point out the danger of greatly reducing or delaying their effectiveness when insecticides, particularly in the form of sprays or dusts, are applied to kill the armyworms.*

It is common knowledge to entomologists and to plantation personnel that long periods elapse, sometimes for a year or more, when armyworms are apparently non-existent over large areas and often on entire islands. During such periods the various parasites which live and multiply at the expense of the armyworms likewise become uncommon. The armyworm moth is a strong flier, fitted and disposed to cover long distances in a short space of time much better than the most effective parasites which normally control it. With the appearance of what is conveniently termed "unfavorable weather conditions" the moth, which is always present in small numbers, although unnoticed, begins to build up populations of armyworms in areas where grass is lush and where parasite populations are at a low ebb. This is the beginning of an outbreak. If "unfavorable weather" continues moths soon fly out widely over cane fields, lay their eggs and start a population of caterpillars where parasites are still scarce, although undoubtedly present in small numbers in or near such fields.

When the early outbreaks occur the armyworms are usually first seen after they have grown considerably and are on the cane and some have already gone

into the ground to transform to moths. Poison sprays or dusts applied at this time usually kill most of the caterpillars above ground but none of those which have gone underground and the poison has no effect on the moths which continue to fly in from adjacent areas. The small numbers of parasites which are already there, and which are endeavoring to multiply on the armyworms, are mostly killed by the poison since the majority of them in their various forms are above ground. New moths which soon hatch from beneath the ground and which also fly in from adjacent fields are then able to start a new generation with little interference by parasites. Outbreaks are inevitable but their duration and frequency can be materially lessened if the many parasites which we now have are allowed to operate to their full capacity. Their life cycles are considerably shorter than that of the armyworm and their potentialities for increase far greater.

There is evidence that the armyworm, *Laphygma exempta*, was much more destructive in Hawaii prior to about 1900 than later. There is no exact record of its first appearance in the Islands. However, it frequently caused much damage to pastures and cane lands by 1873. In the *Hawaiian Almanac and Annual* for 1883, pp. 44-50, appears an article by J. E. Chamberlain in which he describes in detail the egg masses of this moth. From his description there is no mistaking the identity of the species as *Laphygma exempta*. He also discusses the visitation of armyworms during the rainy season of 1873-74 on the plains between Ewa and Waialua and Ewa and Honolulu. At that time the infestations were so heavy that land which had been green with grass became "bare as if scorched" and "cattle starved to death that year." It is of further interest to read in the same article that "no year passes in which the Peelua [Hawaiian name for armyworm] does not inflict great injury, damage and destruction in some district on some island of the group."

It was not until about 1898 that intelligent efforts were begun by entomologists to obtain control of this pest in Hawaii with parasites. This work continued intermittently until 1942, when the last lot of beneficial insects was introduced. As introductions were made from time to time between 1898 and 1942 the outbreaks of caterpillars apparently became less frequent and less prolonged, although it was not until 1942 that control reached a peak in effectiveness. During the period from about July 1942 to January 1948, the longest spell of relief from this pest elapsed since records were first published or notes made on its occurrence in the Territory. There can be only one clear explanation for this—the large increase in the complex of parasites imported for armyworm control. Weather cycles have played a part in the rise and fall of armyworm populations and exceptionally rainy years are generally believed to be favorable for armyworm development; but dry weather alone cannot be accountable for the situation prevailing between July 1942 and January 1948.

To appreciate the actual part played by the natural enemies of armyworms in the suppression of this pest, an exact picture of what they are and how they work is essential. A brief history of these parasites is given below together with a discussion of the habits of each. Once their usefulness is thoroughly understood, the need to preserve and encourage them in our cane fields in every possible manner becomes clearly evident. Most of the information assembled below is from previous publications by several authors.

The first armyworm parasite to be observed by entomologists in Hawaii was

the large grey tachinid fly, *Chaetogaedia monticola* (Bigot), shown in Fig. 1, enlarged about three times. Dr. R. C. L. Perkins found it well established in 1892. It is not definitely known how it reached Hawaii from the west coast of the mainland where it is native. This fly is an enemy of both armyworms and cut-

Fig. 1. Adult *Chaetogaedia monticola* enlarged three times.
(After Swezey, *Experiment Station, H.S.P.A. Ent. Bull. 7*, 1909.)

worms. Dr. O. H. Swezey discovered the interesting manner by which it destroys such caterpillars. Each individual female fly has the capacity of laying about 5,000 eggs. They are placed singly on cane and leaves of other herbage where armyworms may be feeding. The microscopic eggs, which are only about 1/50 of an inch long, are glued to the leaves and appear as minute black specks, as shown in Fig. 2 and greatly enlarged in Fig. 3. When an armyworm eats the portion of a leaf bearing one of these eggs the latter immediately hatches as soon as swal-

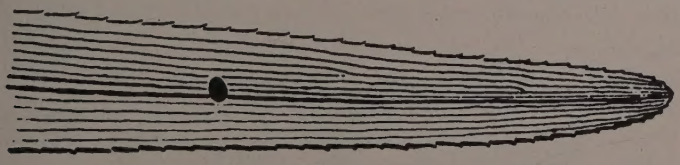

Fig. 2. *Chaetogaedia monticola* egg on leaf enlarged six times.
(After Swezey, *Experiment Station, H.S.P.A. Ent. Bull. 7*, 1909.)

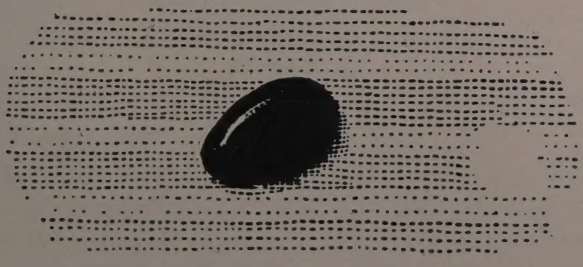

Fig. 3. *Chaetogaedia monticola* egg enlarged 42 times.
(After Swezey, *Experiment Station, H.S.P.A. Ent. Bull. 7*, 1909.)

lowed and the resulting little maggot feeds and grows within the caterpillar, which finally drops to the ground to transform into a moth. But in this it fails, for from the pupa formed by the caterpillar there emerges a single large parasitic fly from 10 to 14 days later instead of the armworm moth. If the caterpillar consumes more than one fly egg, only one succeeds in maturing to a fly.

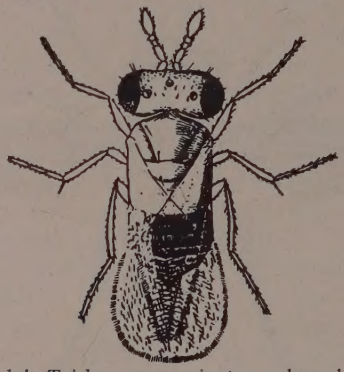

Fig. 4. Adult *Trichogramma minutum* enlarged 100 times.
(After Wolcott, *Entomologie D'Haiti*, 1927.)

The second armyworm parasite, *Trichogramma minutum* Riley, which was observed by entomologists in Hawaii is a very small, yellowish wasp about 1/50 of an inch long which destroys the eggs of the moth. This is shown very greatly enlarged in Fig. 4. It develops in and destroys the eggs of many different kinds of insects, although favoring moths and butterflies. It came from the mainland where it is common and was first seen in Hawaii by Albert Koebele in 1900. This wasp deposits from one to several eggs in each armyworm egg attacked. The larvae of the parasite consume the contents of the egg, then mature to adult wasps which bore out through the egg shell. The life cycle of this little insect is very short. Dr. Swezey found that in Hawaii it may be as short as 10 days.

Fig. 5. Adult *Pseudamblyteles koebelei* enlarged about three and one-third times.
(After Swezey, *Experiment Station, H.S.P.A. Ent. Bull. 7*, 1909.)

The next parasite which has played a part in the control of armyworms in Hawaii is *Pseudamblyteles koebelei* (Swezey). This is a reddish ichneumonid wasp with rather smoky wings measuring about 3/5 of an inch in length. It is

shown in Fig. 5 enlarged somewhat more than three times. Koebele introduced this insect into Hawaii from California probably about 1899. With her sharp ovipositor, the female wasp forces an egg into the body of each caterpillar attacked. This hatches to a larva which remains feeding and growing slowly within the armyworm. The latter does not immediately die but eventually drops to the ground to transform into a moth. In this it fails and from the pupa which it formed there later emerges an adult wasp.

Fig. 6. Adult *Frontina archippivora* enlarged four and one-third times. (After Swezey, *Experiment Station, H.S.P.A. Ent. Bull. 5*, 1909.)

The fourth armyworm parasite, *Frontina archippivora* (Williston), is one of much interest and is believed to have been introduced into Hawaii by Koebele from California about 1898 or 1899. This is a bristly tachinid fly, shown in Fig. 6 enlarged four and one third times. Although slightly larger it may be mistaken by the layman for the common house fly because of the similarity in general size and color. However, in habits it is invariably different. It parasitizes a wide variety of caterpillars. When armyworms appear in a field a close observer will see this fly busily hovering amongst the caterpillars and laying usually from two to five eggs on each worm by which it alights. These eggs quickly hatch to minute maggots which bore into the body and begin absorbing the interior fluids. The caterpillar is thus killed and fails to become a moth. The maggots mature within the body of the armyworm, drop to the ground to form their own puparia, from which later emerge more flies. If the caterpillar is well grown when the fly lays its eggs on it, it succeeds in reaching the ground in time to form the moth pupa; but no moth develops and only flies ultimately come out. This interesting fact was determined by Dr. Swezey. This fly has done much good in Hawaii during the past 48 years.

Between 1900 and 1923 the entomologists were occupied with other and more important matters and nothing further seems to have been done towards a better control of armyworms. Outbreaks of varying intensity continued to occur although not so widely epidemic as in the early days. However, the age of scientific control of everything that had a bearing on sugar yields was rapidly gaining headway and complaints of armyworm damage on the plantations were not infrequent.

In 1923 Herbert Osborn, Assistant Entomologist of the Experiment Station, gave attention to armyworm enemies in Mexico. He found two important parasites which had not been previously introduced into Hawaii. One was a small,

dark, eulophid wasp about 1/10 of an inch long, known as *Euplectrus platyhypenae* Ashm. This is shown enlarged about twelve times in Fig. 7. Osborn sent living material of this wasp to Hawaii during April of that year. J. S. Rosa reared this in the laboratory by the thousands for several years and distributed it to all plantations in the Territory. It became thoroughly established and has been of

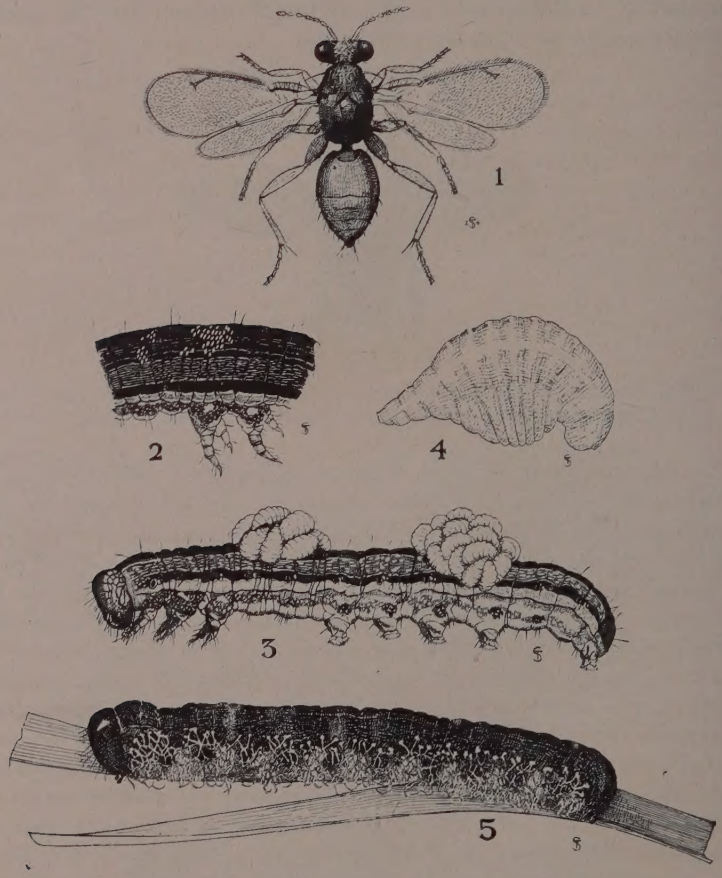

Fig. 7. *Euplectrus platyhypenae*—

1. Adult female enlarged 12 times.
2. Part of an armyworm showing cluster of parasite eggs enlarged over three times.
3. Armyworm bearing two clusters of parasite larvae enlarged two and one-half times.
4. Parasite larva greatly enlarged.
5. Dead armyworm fastened to leaf by the cocoons of the parasites enlarged about two and one-half times.

(After Swezey, *The Hawaiian Planters' Record*, 28, p. 320, 1924.)

distinct benefit. This wasp has the interesting habit of alighting on the armyworm and depositing clusters of minute eggs on the back and sides. Armyworms from one-half to three-quarters grown are selected as victims. From five to 30 eggs are usually placed in each cluster, as shown, greatly enlarged, on a section of a parasitized caterpillar in Fig. 7. The wasp larvae then puncture the army-

worm skin without moving from the spot where hatched and absorb the body fluids of the pest. They grow and swell rapidly until they appear as solid groups of greenish-white larvae massed on the body of the rapidly deflated caterpillar as shown in Fig. 7. The armyworm stops feeding and soon dies in place on the cane or grass leaf. The parasite larvae then crawl beneath and along the sides of the caterpillar skin and spin cocoons from which, in about one week, adult parasites hatch out. The condition of the dead armyworm, as it is attached to a leaf with parasite cocoons beneath it is shown, greatly enlarged, in Fig. 7. The life cycle of this parasite averages about two weeks.

Mr. Osborn also found a large, black carabid beetle at Cuernavaca, Mexico, which was predatory on armyworms and other caterpillars. One shipment was made to Honolulu and thirty individuals in good condition were liberated at Waikii, Hawaii at an elevation of about 4,500 feet. This was on September 25

Fig. 8. Adult *Calosoma blaptoides* subsp. *tehuacanum* enlarged three times.

of that year. These survived and propagated where liberated but the species remained so scarce that it was not seen again until May 1947 when W. C. Look and Dr. Swezey found individuals running over the ground in the general locality where the original specimens were released. Beetles of this type are considered very beneficial where known and it is possible that it is becoming useful against armyworms in the grassy uplands of the Parker Ranch on the island of Hawaii. It has not as yet been seen at lower elevations where cane is grown. Dr. E. C. Van Dyke, Entomologist of the California Academy of Science, has identified this beetle as *Calosoma blaptoides* Putz. subspecies *tehuacanum* (Lapouge). It is shown in Fig. 8, enlarged three times.

During the same year (1923) Osborn found another armyworm enemy of promise in Mexico. This was the large, blackish and grey, tachinid fly, *Archytas cirphis* Curran, shown in Fig. 9 enlarged about five times. This fly is about 1/2-inch long and superficially suggests a bee, both as to size and activity. During February 1924, Osborn sent a few puparia of this fly to the Experiment Station. From these there soon emerged nine flies of this species. These were liberated in Honolulu near the slopes of Punchbowl Crater. A year later the species was found well established on Oahu and during the summer of that year the entomologists moved many of them to the other Islands. It soon became well established on all of the Islands. This parasite has the instinctive habit of depositing tiny maggots on leaves where armyworms are feeding. When an armyworm crawls near one of these maggots the latter quickly attaches itself to the caterpillar and bores into its body where it feeds on the rich nutrients and grows. The armyworm

ultimately drops to the ground to transform to a moth which it fails to do. The caterpillar succeeds in forming a pupa, but from this point development to a moth stops and from the pupa formed by the armyworm there finally emerges one of these large bee-like flies. Somewhat less than a month elapses between

Fig. 9. Adult *Archytas cirphis* enlarged five times.
(After Swezey, *The Hawaiian Planters' Record*, 31, 1927.)

the time the fly maggot penetrates the caterpillar until the fly develops and comes forth from the moth pupa. Dr. Swezey observed during 1930 that about 85 per cent of armyworms in a cane field at Waimanalo, Oahu were killed by this parasite.

Fig. 10. Adult *Hyposoter exiguae* enlarged six times.
(After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*, p. 268, 1931.)

An eighth enemy of armyworms appeared in Hawaii during 1925. It is not known just how it found its way into the Territory, but it probably came on fresh vegetables or other plant material imported from California, where it is known. This is the ichneumonid wasp, *Hyposoter exiguae* (Vier.), shown in Fig.

10 enlarged about six times. The wasp is about 1/4-inch long and black and orange in color. It has the habit of alighting by a young armyworm, stinging it and forcing a single egg into its body. The parasite larva, hatching from this egg, destroys the armyworm by the time the latter is half grown. It then spins a

Fig. 11. *Hyposoter exiguae* cocoons on nutgrass (Cyperus rotundus) about natural size.
(After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*, p. 269, 1931.)

whitish, banded cocoon on the leaf near where the caterpillar has died, as shown in Fig. 11 about natural size. From this an adult *Hyposoter* later emerges. Dr. Swezey has found that the life cycle of this parasite averages from three to four weeks. This parasite attacks and develops on several other moth species in Hawaii.

Fig. 12. Adult *Telenomus nawai* enlarged about 70 times.
(After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*, p. 249, 1931.)

A ninth armyworm parasite in Hawaii is one which often plays a heavy part in the control of this pest. This is the little, black, scelionid wasp, *Telenomus nawai* Ashm., shown very greatly enlarged in Fig. 12. The wasp is about 1/50 of an inch long. It is not known how it entered Hawaii nor from whence it came,

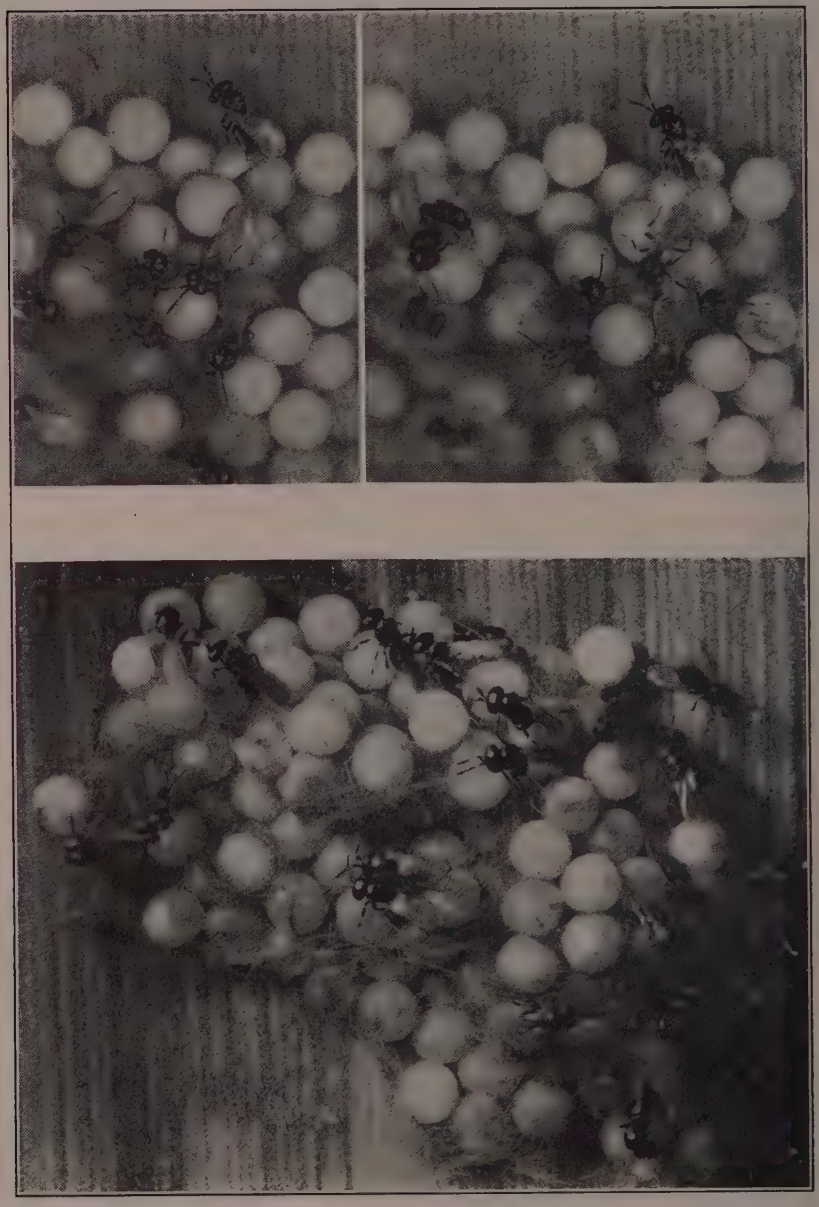

Fig. 13. *Telenomus nawai*, adult females, ovipositing in armyworm eggs enlarged about 25 times. (After Pemberton, *The Hawaiian Planters' Record*, 37, p. 170, 1933.)

but it has been collected in Japan and Fiji. During September 1926, Mr. Rosa observed a number of these wasps moving about over a *Laphygma* egg mass on a cane leaf at the Experiment Station. Further study by Rosa and Pemberton revealed its habits and importance. The wasp was found to sting the moth eggs and deposit into each a single egg of its own. The parasite larva upon hatching fed and developed within the egg and matured to a wasp which then bored a ragged hole in the empty egg shell and emerged. Fig. 13 shows the wasps sitting over moth eggs and actually depositing their own eggs into them. The material is

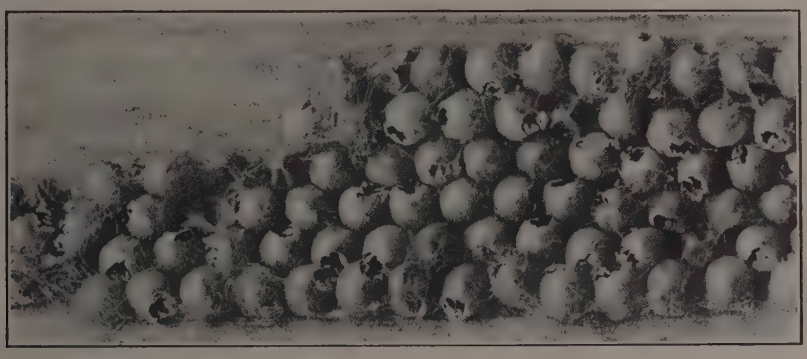

Fig. 14. *Telenomus nawai*, showing armyworm eggs from which parasites have emerged. (After Pemberton, *The Hawaiian Planters' Record*, 37, p. 173, 1933.)

enlarged about 25 times. Fig. 14 shows, greatly enlarged, the appearance of the moth eggs after the parasites have destroyed them. The entire life cycle of this parasite averages about two weeks. Each female is capable of depositing an average of 89 eggs. Its potentiality for increase is thus very great if moth eggs can be found in which to multiply. It has often been determined that this parasite will destroy from 95 to 100 per cent of the moth eggs in localities where it has had time to build up large populations. Mr. Rosa multiplied this parasite in the laboratory by the many thousands and sent them to all sugar plantations, where they became established and the plantations, in many cases, have in past years multiplied it in their own laboratories for distribution in the cane fields.

In spite of the operation of all of the various beneficial insects already mentioned, which without question did much good, armyworms continued to reappear sporadically in our cane fields and with the still further increase in the scientific management of cane culture in Hawaii, it was felt about 1941 that more efforts should be made to obtain better natural enemies of armyworms.

Thus in 1942, F. A. Bianchi, then Assistant Entomologist of the Experiment Station, was instructed to go to Brownsville, Texas, and obtain, if possible, certain armyworm parasites which Federal entomologists had found in that region. In this he was very successful. Of the several species of parasites he found and shipped to Hawaii in good condition, four different kinds became established and at least two have proved to be of great importance.

The first of these was a small, black, braconid wasp with reddish legs. It is known as *Apanteles marginiventris* (Cresson). The wasp is about 1/10 of an inch long and is shown in Fig. 15 enlarged about 15 times. During August and No-

vember 1942, Mr. Bianchi shipped large quantities of this parasite from Brownsville to Honolulu. Some of these were liberated immediately in cane fields while others were saved for breeding in the laboratory. The breeding and distribution of this species continued until the middle of 1943 and over 4,000 adults were thus

Fig. 15. *Apanteles marginiventris*, cocoon and adult enlarged about 15 times. (After Bianchi, *The Hawaiian Planters' Record*, 48, p. 210, 1944.)

liberated. The species became quickly established on all of the Islands. This wasp attacks armyworms as soon as they hatch and while they are still too small in the field to be readily seen. The parasite stings and deposits a single egg into the body of each young armyworm attacked. This hatches to a larva which feeds and grows so rapidly that the armyworm succumbs when only about one-third grown and before it has done much damage to the cane. The parasite larva emerges from the dying caterpillar and usually crawls out towards the tip of the grass or cane leaf and spins a white, cylindrical, silken cocoon. This is firmly attached to the leaf and forms a conspicuous white body about 1/8 of an inch long easily visible to the naked eye. One of these cocoons, enlarged about 16 times, is shown in Fig. 15. The total life cycle of this parasite in Hawaii is much shorter than that of the armyworm. During periods of armyworm scarcity this parasite will maintain itself on several other species of caterpillars occurring in Hawaii.

The second armyworm parasite of importance which Mr. Bianchi collected and shipped to Hawaii during 1942 is the brownish braconid wasp, *Meteorus laphygmae* Viereck, shown in Fig. 16, enlarged about eight times. The wasp, which measures about 3/16 of an inch in length, also attacks and deposits a single egg into very young armyworms. The parasite larva, upon hatching, feeds in-

ternally in the caterpillar and remains until the latter is about three-quarters grown at which time the larva bores out of the armyworm and spins a small, brown, glassy, spindle-shaped cocoon about 1/6 of an inch long. This cocoon is always suspended from a leaf by a delicate, silken thread from one-half to two

Fig. 16. *Meteorus laphygmae*, adult and cocoon, enlarged about eight and twelve times respectively.
(After Bianchi, *The Hawaiian Planters' Record*, 48, p. 207, 1944.)

inches long. The cocoon is shown in Fig. 16 enlarged about 12 times. The adult wasp has already emerged from the cocoon illustrated, which shows a loose cap at the lower end. R. A. Vickery, a Federal entomologist, has reported that this parasite is capable of 18 generations a year and that a single female can parasitize as many as 83 armyworms over a period of nine days. Bianchi sent about 3,200 individuals of this parasite to Honolulu. Most of these were liberated and a few were saved for laboratory breeding. In all a total of 3,900 was sent to the sugar-producing islands. The parasite became well established and is believed to have accomplished much good. It also has the habit of parasitizing several other species of caterpillars in Hawaii and in consequence can maintain itself during times when our common armyworm is extremely scarce.

Another braconid parasite which Bianchi collected and shipped to Hawaii

from Texas in 1942 was *Chelonus texanus* (Cresson). This black wasp is about 1/4-inch long and is shown in Fig. 17 enlarged about nine times. Federal entomologists consider this the most important armyworm parasite in Texas. It also has the ability of parasitizing several different species of caterpillars occurring both in Texas and Hawaii. Bianchi succeeded in getting approximately 900 of these parasites to Honolulu in good condition. Many of these were liber-

Fig. 17. Adult *Chelonus texanus* enlarged about nine times.

ated directly in cane fields and some were saved for breeding in the laboratory, resulting in the total liberation of a large number of individuals, estimated to be at least several thousand. This parasite has been found established on the islands of Oahu and Hawaii and it is most probably established on the other islands also. It has the interesting habit of placing its eggs into the armyworm moth eggs, one to each egg. The moth eggs, so parasitized, hatch to normal caterpillars which nevertheless carry the developing parasite in their bodies. The armyworm continues feeding and growing until somewhat over half size, when, as observed by Mr. Bianchi, it drops to the ground. The parasite larva which has been developing in its body then completes the destruction of the caterpillar and spins a white cocoon at the spot where the armyworm has expired. From this cocoon an adult parasite hatches in from one to two weeks, according to Mr. Bianchi.

A fourth armyworm parasite which Mr. Bianchi shipped to Hawaii from

Texas during 1942 and which has become established at least on the island of Oahu, is the ichneumonid wasp, *Pristomerus appalachianus* Viereck, shown enlarged about four and one-half times in Fig. 18. The wasp is about 1/3 of an inch long. It stings and deposits its eggs into the bodies of young armyworms. The parasite larva upon hatching remains feeding within the caterpillar until the latter is about half grown, when the parasite emerges and spins a smooth, brown, unmarked, cylindrical cocoon slightly over 1/4-inch long, from which in about

Fig. 18. Adult *Pristomerus appalachianus* enlarged about four and one-half times.

two weeks, or less in warm weather, a new parasite escapes. The armyworm is thus destroyed. Bianchi succeeded in getting 65 individuals of this species to Honolulu in excellent condition. These were liberated in cane fields of Kauai and Hawaii. Although established, it has not as yet become conspicuous and has been seen only on Oahu. It is concluded that further study will reveal its presence on Kauai and Hawaii.

Bianchi has discussed in detail his work with the Texan parasites in *The Hawaiian Planters' Record*, Vol. 48, No. 3, 1944, pp. 203-212.

During the year 1942 there appeared on Oahu still another important armyworm parasite. This was the tachinid fly, *Eucelatoria armigera* (Coq.). It bears some resemblance in size and color to the common house fly, although otherwise quite different. It is shown in Fig. 19, enlarged about 14 times. It averages about 1/4-inch in length. In April 1942, R. H. Van Zwaluwenburg and the writer first saw it in a field at Waialua Agricultural Company, Ltd., and recognized it as something new in the Territory. It is a mainland species and probably came to Hawaii as a parasite in some caterpillar infesting imported tomatoes. Dr. F. X. Williams had previously reared it from a caterpillar he found in a California tomato on the market in Honolulu. Within two years it was found widely spread in the Territory. In addition to armyworms it attacks a number of different kinds of caterpillars in Hawaii, notably the new monkey pod moth *Polydesma umbricola* Boisduval. It is an exceedingly aggressive and prolific insect with a life cycle so short that it is easily capable of passing through 20 or

more generations a year in the lowlands of Hawaii. During Mr. Bianchi's investigations of armyworms on the island of Hawaii in May 1948, he found it so common along the borders of a cane field at Honokaa that it was literally visible by the thousands.

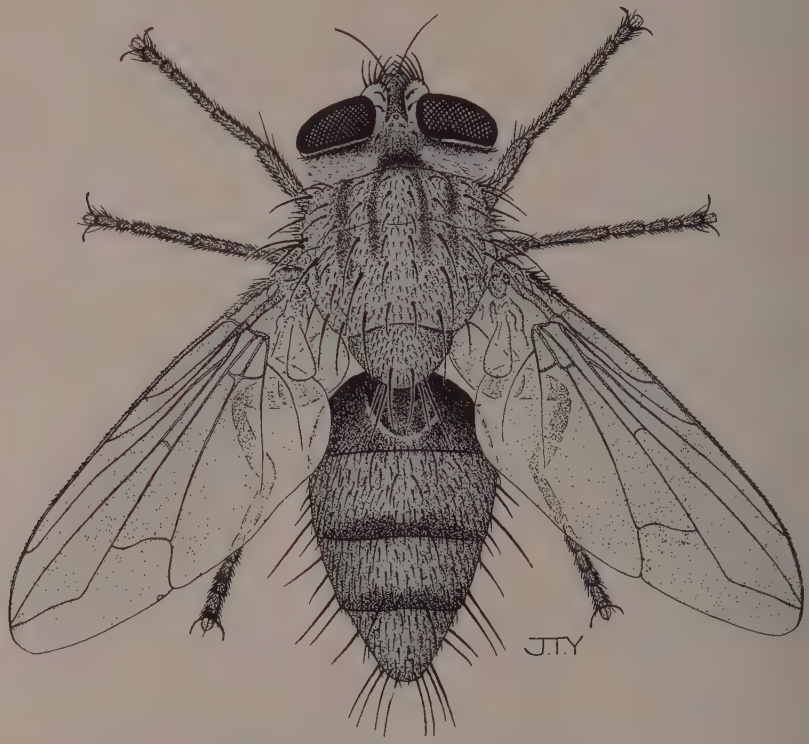

Fig. 19. Adult *Eucelatoria armigera* enlarged about 14 times.
(After Van Zwaluwenburg, *The Hawaiian Planters' Record*, 47, p. 82, 1943.)

Van Zwaluwenburg studied the habits of this fly and reported his findings in *The Hawaiian Planters' Record*, Vol. 47, No. 2, 1943, pp 81-87. He found that the female bears a sharp, grooved, thorn-like structure, near the tip of the abdomen, with which it stings or pierces the skin of armyworms with lightning-like swiftness and in the same instant ejects into them, through this grooved organ, from one to several well-developed living maggots. The appearance of this peculiar, thorn-like larvipositor is shown in Fig. 20, greatly enlarged, after it has been dissected from the fly. Van Zwaluwenburg determined that the maggots only require from 3.2 to 5.4 days to kill the armyworms and from seven to nine days more to mature to flies.

Mention should be made of the large vespid wasps of the genus *Polistes*, which at times become conspicuous in armyworm-infested fields. These are reddish-brown with yellow marks, or yellow and black, according to species. One is shown in Fig. 21, twice enlarged. These are often referred to as caterpillar-skinning wasps because of their habit of grasping caterpillars and deftly skinning

them, thence to carry away the skin and adhering tissue to feed to their young. These came to Hawaii from the mainland prior to 1900.

From the present discussion it is seen that there are at least 15 different insect enemies of the common armyworm in Hawaii. These collectively are capable of increasing to overwhelming numbers when armyworm outbreaks

Fig. 20. *Eucelatoria armigera*. Lateral view of larvipositor of female greatly enlarged. (After Van Zwaluwenburg, *The Hawaiian Planters' Record*, 47, p. 83, 1943.)

occur. When such visitations follow long periods of armyworm scarcity, the maximum effectiveness of the parasites cannot be expected until the pest has usually passed through several generations in any given area. If decision is made to use poisons rather than wait for the inevitable control by parasites, the cost of applying the insecticides should be weighed against the estimated damage to the crop if nothing were done. In important experimental tests, as in differential fertilizer studies, there can be no recourse but to apply insecticides as soon as armyworms appear.

Fig. 21. Adult *Polistes fuscatus*, var. *aurifer* enlarged two times.
(After Williams, *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields*, p. 243, 1931.)

When it is felt that poisons must be used over large areas it is recommended that poison baits be spread, in preference to the use of sprays or dusts. Baits cannot materially interfere with the activities of the egg parasites or several of the larval parasites above discussed, whereas sprays or dusts will cause a heavy mortality amongst all of them.

No discussion of the natural enemies of armyworms would be complete without mention of the so-called "Wilt Disease." Investigators have established

proof that the typical wilt diseases of caterpillars are caused by a filterable virus. Epidemics of this disease periodically appear amongst armyworms in Hawaii. It usually occurs in the field after armyworms have gone through several generations. In laboratory breeding of armyworms in order to multiply parasites, the disease sometimes appears and quickly wipes out the caterpillars. Mr. Rosa has noted that this most often happens when caterpillars become too crowded in the rearing jars. Caterpillars so affected turn black and hang limp and dead on the leaves. The body is filled with a dark, evil-smelling liquid. Efforts to propagate and utilize this virus in the field have not been attended with success. The natural presence of the disease in the field is probably one of the factors accountable for the final disappearance of armyworms after repeated outbreaks.

TABLE I

SUMMARY

Type of Parasite	Distinguishing Characteristics	Method of Attacking Armyworms	Average Life Cycle	Relative Importance
A. WASPS—				
Trichogramma minutum (Fig. 4)	Yellowish. 1/50-inch long	Lays egg in armyworm egg	12 days	Third
Pseudamblyteles koebelei (Fig. 5)	Reddish with smoky wings. 3/5-inch long	Parasite of fair-sized larvae	3 weeks	Fourth
Euplectrus platyhypenae (Fig. 7)	Black and yellow. 1/10-inch long	Lays clusters of eggs on ½- to ¾-grown larvae	2 weeks	Third
Hyposoter exiguae (Figs. 10-11)	Black and orange. ¼-inch long	Lays egg into body of young larvae	3 to 4 weeks	Third
Telenomus nawai (Figs. 12-13-14)	Jet black. 1/50-inch long	Lays egg in armyworm egg	2 weeks	Second
Apanteles marginiventris (Fig. 15)	Black. 1/10-inch long. White cocoon on leaf	Lays egg in body of very young larva	3 weeks	First
Meteorus laphygmae (Fig. 16)	Yellowish. 3/16-inch long. Brown cocoon hung on leaf with thread	Lays egg in body of very young larva	3 weeks	First
Chelonus texanus (Fig. 17)	Black. ¼-inch long	Lays egg in armyworm egg	3 weeks	Fourth
Pristomerus appalachianus (Fig. 18)	Blackish, slender. ⅓-inch long	Lays egg in body of young larva	3 weeks	Fourth
Polistes Wasps (Fig. 21)	Reddish or yellow and black. Robust. ¾-inch long	Skins caterpillars	5 weeks in summer	Fourth

TABLE 1

SUMMARY (Continued)

Type of Parasite	Distinguishing Characteristics	Method of Attacking Armyworms	Average Life Cycle	Relative Importance
B. FLIES—				
Chaetogaedia monticola (Figs. 1-2-3)	Large grey fly. Over ⅜-inch long	Lays eggs on leaves. Eggs swallowed by larva while feeding	3 weeks	Third
Frontina archippivora (Fig. 6)	Bristly grey fly. Resembles house fly	Lays eggs on larva	3 weeks	Third
Archytas cirphis (Fig. 9)	Black and grey. Bee-like. ½-inch long	Lays maggots on leaves. Maggots bore into larvae	4 weeks	Second
Eucelatoria armigera (Figs. 19-20)	Grey fly. Resembles house fly	Stings and injects maggots into fairly well-grown larvae	2 to 3 weeks	First
C. BEETLE—				
Calosoma blaptoides (Fig. 8)	Large, black, wingless beetle. 1¼-inches long	Lives on ground mostly and eats armyworms	Several weeks	Unimportant to date

Note: The relative importance of the various parasites will vary from time to time and from place to place.

A Key to Rain Gages in Hawaii*

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Climatological data are only infrequently fully exploited for agricultural and industrial uses. This is partly due to lack of available techniques for application of such data to specific problems. Far more important, however, is the general lack of adequate basic data.

Hawaii is fortunate in that a relatively great mass of basic data on rainfall and temperature has been accumulated. It is true that portions of such data are not quite as complete and accurate as one might like. On the other hand, the large volume tends to compensate for some of the deficiencies.

The greatest impediment to the use of the climatic data of Hawaii is the fact that only a portion of the existing data is published. Important segments, in fact two thirds of all the records, exist only in the files of the many plantations and ranches which collect the data.

When the authors attempted to use these unpublished data for research purposes, it became clear that a large organizational job was necessary before the data on daily rainfall values could be analyzed. To study geographic distribution of rainfalls day by day, it is clear that the exact locations of the gages, the frequency and time of reading are very important. The purpose of the maps and tables presented here is to guide all those interested in Hawaiian rainfall away from the pitfalls which might arise from the kinds of difficulties indicated by the following examples.

1. Confusion in the names of stations.

   The U. S. Weather Bureau publishes daily rainfall records from two stations on Maui known as "Kihei" and "Camp K-3" respectively. Both gages are owned and operated by the same plantation. The plantation has for many years called the former "Camp 19" and the latter "Kihei." Obviously if one uninformed of this matter were to use the records, he would assume that "Kihei" of the plantation records is the same as "Kihei" published by the Weather Bureau.

2. Station location errors.

   The plantation map showed a particular gage to be at a certain location. The persons who tabulated the data in the plantation office believed that

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the location shown was correct. However, the rainfall measured by the gage seemed to be too high for the location shown on the map. Therefore, the plantation engineer and the authors made a field check which involved an all-day hike on a mountain trail. It was found that the gage lay two miles further into the mountains than the plantation map indicated. This difference in location affected the elevation, and might have proved a considerable source of annoyance in research had the error not been corrected.

Though the organization of records for those gages now discontinued is important, first priority logically should go toward gages now extant. In nearly all cases, the rain gages having long records are still in operation.

The task of collecting and publishing past records now unpublished would be enormous. In lieu of this, a list of available data is presented here. The accompanying maps show the locations of all stations operating in 1948 and indicate how frequently the gages are read. The maps are keyed to the tabulations which present various characteristics of the record. The material presented here requires certain explanation which will assist the student of these records in evaluating their reliability, and will point out the limitations of the maps and tables. These explanations follow in succeeding paragraphs.

Station Name and Number

For purposes of the present paper, the authors have numbered each station. The numbering system provides a way of locating a gage geographically. The numbers run from one to 1145, proceeding from south to north up the island chain. Within each five-minute latitude band, however, numbers proceed from west to east. This geographic pattern of numbering can be seen on inspection of any of the accompanying maps.

If the name of a station is known and its location desired, the station number may be determined from the alphabetical list.

The numbers occurring on each island are as follows:

Island	Station Numbers	Actual Number of Gages (1948)
Hawaii	1-223	221
Maui	248-497	167
Molokai	500-563	49
Lanai	650-696	34
Oahu	700-912	232
Kauai	925-1145	124

Many numbers between one and 1145 are unused or unassigned. Blocks of numbers were left open to allow for future changes as new gages might be installed or gages now unknown come to our attention. The preparation of these tables and maps has been a gradual process. Because maps of individual islands have been reproduced for research purposes during the progress of the present compilation, slight non-uniformity in the geographic pattern of number assignment still exists. The use of A or B after a station number was necessary in certain areas where blocks of unassigned numbers became exhausted. Neverthelesss, the progression from north to south has been maintained, and within each five-minute latitude band the progression of numbers from west to east has been

approximately maintained. The net result still allows easy spotting of a station if its number is known.

Gages on plantations are occasionally moved without any note in the record to show it. Often the same name is applied to the new location. No check on such past changes was possible, and this source of error should be kept in mind by the research worker.

The station name often leads to confusion. Plantations and ranches always have a name or number for each of their rain gages. In many cases, a gage will be known by two or three names, different persons using different names for the same gage.

For purposes of publication, the Weather Bureau generally adopts the policy of giving a rain gage a name which bears some geographic significance. This system usually is of real help, but in Hawaii it has led to some unfortunate confusion. Since no complete list of all operating gages was available, the name assigned to a given gage might also be used by a plantation to mean some different gage.

Because all gages, the records of which are published, have been included in the accompanying tables, the Weather Bureau's published name is the one used by the authors. However, in the tables, all known alternate names have been listed. Though this means that the generally accepted plantation name might appear only as an alternate name, the adoption of the published name as the official one has the advantage of making the published records easier to use in connection with the maps and tables.

Station Elevation

The authors found that plantation personnel can furnish a correct field location on a good base map but elevation for the station may not have been determined. The elevations listed in the tables have in most instances been derived by checking the following two values: (1) the elevation taken from the topographic base map on which the stations were plotted; (2) the elevation listed by the plantation or gage keeper. Where the topographic features of the base allowed a good determination of elevation, this one was used in preference to that listed by the gage owner. On the whole, elevations in the accompanying tables can be trusted within 50 feet. In steep country, however, elevations should not be assumed to be closer than 100 feet. Elevations shown in the table have been rounded out to the nearest 10 feet, and for most of the low stations, accuracy within 10 feet probably holds.

Length of Record

The tables and maps show only stations operating in 1948. The first year of record is noted, but in some cases the record might be interrupted for short periods.

The data for inclusion in this column were supplied by the plantations, ranches, and individuals keeping the record. In general, the length of record shown here can be considered trustworthy with the possibility of interruptions of a few months in certain cases.

The present data constitute a companion tool to be used in conjunction with the tabulations presented in the Territorial Planning Board Report (1939). That report listed average monthly and annual rainfall values for an incomplete list of stations. However, it contains data on stations now discontinued which the present paper does not list.

Time and Frequency of Reading

The Weather Bureau generally does not publish the daily record of a rain gage unless the gage is actually inspected each day, whether or not it rained. In Hawaii, however, it is common practice to read gages only after a rain, or about once a week in case of no rain. It is clear that this practice leads to some error because in certain cases the observer may not know that it rained over the gage. Spottiness of shower-type rainfall enhances this possibility.

On the other hand, at least some gage records published by the Weather Bureau as daily amounts are actually for readings made after each rain and not each day, all unbeknown to the Bureau. There are also many gages read each day, the records of which are not published.

In the present tables, a differentiation is made between daily-read gages and those read after each rain. On the maps, however, these classes are combined and shown by one symbol. The maps differentiate between recorders, gages read daily or after each rain, and those read weekly, monthly or intermittently.

Time of day at which daily gages are read is noted in the tables. This information was supplied by the plantations or persons keeping the gage.

There is the possibility of confusion arising from the dating of daily rainfall values. It is the practice of the Weather Bureau to record a rainfall value opposite the day on which the gage is read. For example, if a rain gage is read at 8:00 A.M., January 15, the rain measured is recorded opposite the date of January 15.

Plantations in Hawaii have for many years used what the authors have called "plantation standard" of rainfall dating. Since the largest number of hours belonged to the previous day, in the above example rain read at 8:00 A.M. January 15, would be entered opposite the date of January 14.

Unpublished daily records in Hawaii can generally be classified as "plantation standard" prior to 1948. Plantations which kept the gage records published in "Climatological Data" usually moved the dates one day forward in filling out Weather Bureau Form 1009. Therefore, records for a given gage kept in the plantation office will usually be on "plantation standard," while the copies of the same record turned in to the Weather Bureau were moved one day to "Weather Bureau Standard."

Beginning January 1948, all plantations were asked to shift to Weather Bureau Standard, dating rains as of the day the gage was read. It is believed that all records are now being kept the same way, but the research worker should keep in mind the possibility of individual discrepancies.

Map Locations

The location maps published in the Territorial Planning Board Report show station locations only in a general way, owing to large symbol size compared with map scale. Also locations of some stations listed in that report are not shown on the map.

Considerable field checking was done in the preparation of the maps presented here. By no means all of the gages were visited, but in nearly every case where real doubt existed concerning the location, a field investigation was made. In a few cases, doubt was diminished by correspondence with the persons keeping the gage. Surely some errors still exist in the present tabulations and maps, but the field checks have reduced these.

Original Sources and Filing of Data

The original maps on which station locations were plotted consisted of the U.S.G.S. topographic sheets, scale 1:62,500, with contours of 100 feet. These work maps were traced on cloth. Both the original work sheets and the cloth tracings will become part of the permanent file of the library of the Experiment Station, Hawaiian Sugar Planters' Association, Honolulu, T. H. They will be kept for the use of interested persons and will be made available to anyone upon application to the librarian of the Experiment Station.

The original survey was expedited by the use of a rainfall record book and survey form distributed to all plantations and ranches in the Territory. On these forms the companies described each gage and subsequently entered daily and monthly rainfall values. The original sheets bound in the books were kept by the individual companies. Carbon copies were collected. The survey forms listed for each rain gage the name, island, elevation, period of record, location, time of reading, and alternate names. Each month subsequent to January 1948 the records of all rain gages are entered in the book and the carbon copies are mailed to a central collection agency. Therefore, formerly unavailable and unpublished data on rainfall since 1948 are currently available in a central place. These records and the survey forms are also available in the library of the Experiment Station, H.S.P.A.

Acknowledgments

The data presented here were supplied by the many pineapple and sugar companies, ranches, and individuals who keep climatic records. Though a complete list would be too lengthy for inclusion here, the help of the many individuals is deeply appreciated.

The drafting of the maps was done by Jacob Chu who handled his portion of the work with a thoroughness stemming from personal interest and the finesse of professional pride.

During various phases of the field work, the authors were assisted by Wendell A. Mordy, M. H. Halstead, and Alice Green. In the office work Wilma Webb was an invaluable asset.

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HAWAII RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
1	Ka Lae	20	U. S. Coast Guard	1925	Afternoon	Daily	Daily	
2	Manuka	1700	Terr. Div. of For.	1928		Monthly	Monthly	
2A	Pahipa Gage	7000	Kahuku Ranch			Monthly		Sheep Station
2B	#3 Mauka Watershed	5100	Kahuku Ranch			Monthly		
3	South Point Corral	250	Hutchinson Sugar	1948		Twice Weekly		
3A	#3 Makai Watershed	4100	Kahuku Ranch			Monthly		
3B	#1 Watershed	3400	Kahuku Ranch			Monthly		
4	Kamaoa	1100	Hutchinson Sugar	1945		Daily	Daily	
4A	Kahuku Ranch House	1950	Kahuku Ranch			Monthly		
5	Kamaoa (Ranch House)	1300	Hutchinson Sugar	1925		Daily		
6	Kiolakaa (A & F)	2000	Terr. Div. of For.	1929	7-8 a.m.	Daily	Monthly	
7	Kiolakaa	1785	W. H. Hayselden	1929	Afternoon	Daily	Daily	
9	Punaluu Kahawai	6250	Terr. Div. of For.	1928		Quarterly		
10	Mountain House	3500	Hutchinson Sugar	1925		Periodically		
11	Makino	220	Hutchinson Sugar			Daily		
12	Kaalaiki	1750	Hutchinson Sugar	1939		Daily	Daily	
13	Waiubata	1750	Hutchinson Sugar			Daily		
14	Naalehu	673	Hutchinson Sugar	1890	7-8 a.m.	Daily	Daily	
15	Hanuapo	50	Hutchinson Sugar			Daily		
16	Moaula Tunnel	2900	Hawaiian Ag. Co.	1923		Monthly		Moaula Mountain
17	Moaula Reservoir	1950	Hawaiian Ag. Co.	1911	6-7 a.m.	Daily		
18	Moaula Station	550	Kapapala Ranch	1920		Monthly	Monthly	Moaula
20	Alili Tunnel	2800	Hawaiian Ag. Co.	1942		Monthly		
21	Pahala	850	Hawaiian Ag. Co.	1885	6-7 a.m.	Daily	Daily	Haw. Ag. Co. Office
22	Keaiwa	1650	Hawaiian Ag. Co.	1911	6-7 a.m.	Daily		Keaiwa Camp, Keaiwa Section, Luna
25	Pahoehoe	1000	Lyman P. Lincoln	1930		Daily	Daily	
26	Takashiba	2400	Kona Experiment St.	1930		Weekly		
27	Honaunau	1090	Mrs. Malae W. Hua	1938	Afternoon	Daily	Daily	
28	Napoopoo	450	Kona Experiment St.	1939	8 a.m.	Daily	Daily	
29	Kaawaloa	1500	D.M. Frazer	1901		Daily	Daily	Was Kealakekua before 1942

156° 00'

45'

30'

15'

155° 00'

20° 00'

19° 00'

KOHALA SUGAR CO

HAWI

KOHALA

PUU HUE RANCH PARKER

KAHUA RANCH

KAWAIHAE

KAMUELA

HONOKAA SUGAR CO

PAAUHAU

PAAUHAU SUGAR CO

HONOKAA

HAMAKUA MILL CO.

KAIWIKI SUGAR CO

OOKALA

LAUPAHOEHOE SUGAR CO

LAUPAHOEHOE

PAPAALOA

UMIKOA

KUKAIAU RANCH

CHOW AND NOBRIGA

PARKER RANCH

HAKALAU PLANTATION CO

HAKALAU

HONOMU

HONOMU SUGAR CO

PEPEEKEO SUGAR CO

PEPEEKEO

ONOMEA SUGAR CO

HILO SUGAR CO

HILO

WAIAKEA MILL CO.

MAUNA KEA

MT. WAAWAA

PUU WAAWAA

HUE HUE

MT. HUALALAI

F GREENWELL

KAILUA

PARKER RANCH

H.N. GREENWELL

AINAHOU W.H SHIPMAN

KEAAU RANCH

OLAA SUGAR CO

PAHOA

OLAA S C

KEALAKEKUA

A. GREENWELL

MAUNA LOA

HAWAII NATIONAL PARK

Mc CANDLESS

KAPAAPALA RANCH

KILAUEA

HONAUNAU

KAHUKU RANCH

MAGOON

COOYEE HOP

KAU FOREST RESERVE

HAWAIIAN AGRICULTURAL CO.

PAHALA

McWAYNE RANCH

HUTCHINSON SUGAR

NAALEHU

KIOLAKAA RANCH

KAALUALU RANCH

MILES 0 2 4 6 8 10

EXPLANATION OF SYMBOLS

- A single circle is a gage read daily or after each rain
- A double circle is a recording rain gage
- A triangle is a gage read weekly, monthly, or intermittently
- The longer dashes are field boundaries or property lines
- The series of dots are the primary roads

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HAWAII RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
30	Komakawai	6150	McCandless Ranch	1944		Monthly	Monthly	
31	Hapuu	4680	McCandless Ranch	1944		Monthly	Monthly	
35	Wood Valley Tunnel	3400	Hawaiian Ag. Co.	1923		Monthly		Naguchi
36	Kapapala Ranch	2100	Kapapala Ranch	1904		Monthly	Monthly	
37	Pakao	5000	" "	1928		Monthly	Monthly	
38	Ainapo	3675	" "	1924		Monthly		
38A	Truck Trail	6750	Hawaii Nat. Park	1948		Twice Monthly		
43A	Maunaiu	4500	Kapapala Ranch	1925		Monthly		
44	Ohaikea	3460	" "	1924		Monthly		
45	Kekekaniho	4700	" "	1925		Monthly		Six Tanks
45A	Lava Flow	5500	Hawaii Nat. Park	1944		Twice Monthly		
51	Wentworth	4025	C. K. Wentworth	1945		Twice Monthly		
51A	Keauhou	3900	W. H. Shipman, Ltd.	1938	6 a.m.	Daily	Daily	
52	Halemaumau	3650	Hawaii Nat. Park	1932		Twice Monthly	Monthly	
52A	Observatory	4000	" " "	1948		Daily		On crater rim
54	Volcano Observatory	3970	" " "	1912	8 a.m.	Daily	Daily	Headquarters (as called by H.N.P.) record kept by the Volcano House Hotel; *not* the "Observatory" gage as called by H.N.P. and which is on the crater rim.
54A	Ohialani Dairy	3780	Margaret C. English		7:30 a.m.	Daily		
58	Ainahou	3000	W. H. Shipman	1944	6 a.m.	Daily		
58A	Ainahou 2	2600	W. H. Shipman	1944		Monthly		
65	Pahoa	670	Olaa Sugar Co.	1915	6 a.m.	Daily	Daily	
66	Kapoho Mauka	400	Olaa Sugar Co.	1934	6 a.m.	Daily		
67	Kamaile	450	" " "	1929	6 a.m.	Daily		
68	Holualoa Beach	10	Puu Waawaa Rch.	1938	4 p.m.	Daily		
68A	Kailua (Puu Waawaa)	10	Puu Waawaa Ranch	1918		Daily		
68B	Kailua (Kona E. S.)	500	Kona Experiment St.	1930	8 a.m.	Daily	Daily	
68C	Lanihau	1500	Kona Experiment St.	1930	8 a.m.	Daily		

HAWAII RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
69	Kahaluu Beach	10	Puu Waawaa Ranch	1938	4 p.m.	Daily		
69A	Ohia Liilii	4500	Hue Hue Ranch			Monthly		Ohia Liilii Paddock
69B	Kaholu	1100	Kona Experiment St.	1930	8 a.m.	Daily		
70	Holualoa	3300	Terr. Div. of For.	1929		Monthly	Monthly	
70A	Halepiula Shed	4500	Puu Waawaa Ranch	1938		Twice Weekly		
70B	Kaalapuali	3700	Frank Greenwell	1937		Monthly		
70C	Holualoa (Twigg-Smith)	1100	Twigg-Smith	1948	7 a.m.	Daily		
71	Honuaula	6520	Terr. Div. of For.	1928	7-8 a.m.	Daily	Monthly	Honoalaa
71A	Waihou 1	3350	Puu Waawaa Ranch	1921		Twice Weekly		
72	Hualalai	8190	Terr. Div. of For.	1929		Monthly	Monthly	
73	Puu Lehua	4850	W. H. Greenwell	1927		Monthly	Monthly	
73A	Keauhou 2	1930	Mac. Nut Co.	1927				
73B	Kainaliu	1500	Kona Experiment St.	1931	Afternoon	Daily	Daily	
74	Kanahaha	5060	W. A. Greenwell	1927		Monthly	Monthly	
75	Ahua Umi	5250	W. A. Greenwell	1927		Monthly	Monthly	Ahua Umi Heiau; Umi Temple
77	Papaloa	5100	Arthur Greenwell			After Rain		
78	Kulani School Site	5650	Terr. Div. of Inst.	1947		Weekly	Monthly	Boys School
79	Kulani Camp	5150	Terr. Div. of Inst.	1947	7-8 a.m.	Daily	Monthly	
80	Kalaieha	6750	Parker Ranch	1914		Daily		Humuulu Sheep Station
81	Kulani Ditch	5100	Terr. Div. of Inst.	1947	7-8 a.m.	Daily	Monthly	Formerly called Kulani Cone (crater); moved to present location about June 1, 1948
82	Puu Oo	6300	W. H. Shipman	1907	6 a.m.	Daily		
86A	Hilo	40	C. E. R. Martin	1880		Daily	Daily	
87	Hilo Airport	20	C.A.A.			Daily		
87A	Waiakea Mill	50	Waiakea Mill Co.	1891	5 p.m.	Daily	Daily	Waiakea Mill Camp 1
88	Waiakea	2000	Olaa Sugar Co.	1930		Irregular	Monthly	Olaa-Kaumana; Flume House
88A	Kaumana	1100	Hilo Sugar Co. (U.S.E.D.)			Recorder		
89	Piihonua	1700	Terr. Div. of For.	1925		Monthly	Monthly	

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
89A	Waiakea Mill Camp 6	600	Waiakea Mill Co.	1900	5 p.m.	Daily		
90	Hilo Sugar Co.	150	Hilo Sugar Co.	1894	6-8 a.m.	Daily		Manager's yard
91	Mountain View	1530	Olaa Sugar Co.	1901	6 a.m.	Daily	Daily	
91A	Keaau	15	W. H. Shipman	1920	6 a.m.	Daily		
92	Olaa	250	Olaa Sugar Co.	1901	8 a.m.	Daily	Daily	Olaa Mill
92A	Huehue	2020	Huehue Ranch	1903	6 a.m.	Daily	Daily	
93	Kapoho	110	Olaa Sugar Co.	1920	6 a.m.	Daily	Daily	Kapoho Makai
93A	Puuanahulu	2130	Puu Waawaa Ranch	1942	4 p.m.	Daily		
94	Hilo Tree Nursery	35	Terr. Div. of For.	1927	7-8 a.m.	Daily		
94A	Puu Waawaa	2750	Puu Waawaa Ranch	1894	4 p.m.	Daily	Daily	
95	Puuhinei 2	2100	Parker Ranch	1941		After Rain		Grass Plot
95A	Puako	12	Ichiro Goto	1939	Afternoon	Daily	Daily	
96	Puuhinei	2400	Parker Ranch	1936		After Rain		
97	Keamoku	3100	Parker Ranch	1908		Daily		
100	Waikii	4500	Parker Ranch	1895		Daily		
102	Puuanuanu	5900	Parker Ranch	1936		After Rain		
102A	Puu Laau	7300	Terr. Div. of For.	1932		Monthly	Monthly	Record goes to Parker Ranch also
103	Makahalau	3900	Parker Ranch	1910		Daily		
104	Kemole 2	5900	" "	1936		After Rain		
105	Kemole 1	4750	" "	1936		After Rain		
106	Old Dairy	4250	" "	1909		Daily		Paleihookapapa
107	Pohakuloa	6750	Terr. Div. of For.	1938	7-8 a.m.	Daily	Monthly	Record goes to Parker Ranch also
110	Puunoho	4250	Parker Ranch	1936		After Rain		
111	Halepohaku	9500	Terr. Div. of For.	1939		Monthly	Monthly	Record goes to Parker Ranch also
112	Hanaipoe	5100	Parker Ranch	1910		After Rain		
113	Puu Mali	7000	Kukaiau Ranch	1933		Monthly	Monthly	Puu Nau
114	Hope-A	4000	" "	1933		Monthly	Monthly	Hope-A Tanks
115	Stone Corral	5250	Kukaiau Ranch	1933		Monthly	Monthly	
116	Papa	4800	Kukaiau Ranch	1944		Monthly		Cistern

HAWAII RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
117	Halepiula	6000	Kukaiau Ranch	1933		Monthly	Monthly	
118	Umikoa	3520	" "	1899	7 a.m.	After rain	Monthly	
120	Puu Kihe	7800	Kukaiau Ranch	1933		Monthly	Monthly	
121	Iolehaehae Tanks	6250	" "	1933		Monthly		
122	Laaumai	6700	Parker Ranch			Irregular		
123	Kaala	5500	Kukaiau Ranch	1933		Monthly	Monthly	
124	Keanakolu	5300	Terr. Div. of For.	1929	7-8 a.m.	Daily	Monthly	Record goes to Parker Ranch also
125	Hopuwai	6400	Parker Ranch			Irregular		
125A	Puakala	6200	W. H. Shipman	1907	6 a.m.	Daily		
126	Maulua	5400	Kukaiau Ranch	1933		Monthly	Monthly	
127	Puu Loa	2550	Kukaiau Ranch	1933	7 a.m.	Daily		Camp 3
128	Nauhi Gulch	5250	Terr. Div. of For.	1925		Monthly	Monthly	Nauhi
130	Ookala (1750)	1750	Kaiwiki Sugar	1936	6-7 a.m.	Daily		Ookala Mauka; Fld. 12
132	Kihalani	1550	Laupahoehoe Sugar	1944	9-10 a.m.	Daily except Sundays		Ben De Mello; Kihalani Mauka
133	Papaaloa	290	Laupahoehoe Sugar	1906	7:30-8 a.m.	Daily except Sundays		Papaaloa Office
134	Makahanaloa 2 (Mauka)	2750	Terr. Div. of For.	1934		Monthly	Monthly	
135	Hakalau (Mauka)	1250	Hakalau Plant. Co.	1920	Afternoon	Daily	Daily	
136	Honomu	1650	Terr. Div. of For.	1926		Monthly		
137	Honohina	300	Hakalau Plant.	1894	Afternoon	Daily	Daily	
138	Honomu (Mauka)	1100	Pepeekeo Sugar Co.	1911	6-7 a.m.	Daily	Daily	Honomu 2; Camp 11
140	Pepeekeo (A & F)	1500	Terr. Div. of For.	1926		Monthly		Pepeekeo Forester's House; Makahanaloa 1
140A	Papaikou (Mauka)	1400	Onomea Sugar	1913	7 a.m.	Daily	Daily	Makalua Mauka
141	Pepeekeo (Mauka)	900	Pepeekeo Sugar Co.	1947	6-7 a.m.	Daily	Monthly	Maukaloa Camp; Pepeekeo 2
142	Hakalau	150	Hakalau Plant.	1920	Afternoon	Daily	Daily	
143	Honomu (Makai)	350	Pepeekeo Sugar	1921	6-7 a.m.	Daily	Daily	Honomu
144	Pepeekeo	150	Pepeekeo Sugar	1890	6-7 a.m.	Daily	Daily	Pepeekeo Makai; office
144A	Papaikou	200	Onomea Sugar	1913	7 a.m.	Daily	Daily	Papaikou Makai

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
145	Ditchmans Stable	500	Hilo Sugar Co.			Daily		
147	Beach	10	Kahua Ranch	1931	10-11 a.m.	After rain		Kahua 4; Waikailio
147A	Middle Pen	1500	Kahua Ranch	1931	10-11 a.m.	After rain		Kahua 3; Lauwai Paiki
148	Kawaihae	50	" "	1937	9-11 a.m.	After rain		Kawaihae 4
148A	Puu Hanae	1400	" "	1935	9-11 a.m.	After rain		Kawaihae 3; Round pen
159	Mahukona	11	Agent; Mahukona Term.	1912	Afternoon	Daily	Daily	
159A	Honoipu	200	Kahua Ranch	1942	8 a.m.	After rain		Plantation Section 2
160	Sta 3 (Kohala Sug.)	200	Kohala Sugar Co.	1940	6:30 a.m.	Daily		Upolu 5, below RR
160A	Upolu Airport	10	C.A.A.			Daily		
161	Puakea	600	Parker Ranch			Daily		
162	Sta 2 (Kohala Sug.)	425	Kohala Sugar	1941	6:30 a.m.	Daily		Upolu 17
162A	Kokoiki	800	Kahua Ranch	1942	8 a.m.	After rain		Plantation Section 1
163	Sta. 15 (Kohala Sug.)	850	Kohala Sugar	1925	7:30 a.m.	After rain		Puakea Res. 2
164	Sta. 9 (Kohala Sug.)	1350	" "	1925	7 a.m.	Daily		Homestead; Kaauhuhu
165	Sta. 4 (Kohala Sug.)	300	" "	1940	6:30 a.m.	Daily		Upolu 13; #7 Res.; Hoea
166	Sta. 14 (Kohala Sug.)	165	" "	1925	6:30 a.m.	Daily		Hoea Mill
167	Puuokumau	1800	" "	1925	6 a.m. & 4 p.m.	Daily	Daily	Puuokumau Res.; Sta. 10
168	Hawi	600	" "	1888	5:30 a.m.	Daily	Daily	Sta. 1; Hawi Office
170	Puuhue	2200	Parker Ranch	1932		Daily		
171	Sta. 5 (Kohala Sug.)	425	Kohala Sugar	1940	7:30 a.m.	Daily		Alaalae 253; Cross roads
172	Sta. 17 (Kohala Sug.)	1450	" "	1923	7:30 a.m.	After rain Weekly		Nunulu Nui; Union Uka
173	Sta. 16 (Kohala Sug.)	450	" "	1892	7 a.m.	Daily		Union Office; Union Park
174	Sta. 6 (Kohala Sug.)	200	" "	1923	7 a.m.	Daily		Union Station
175A	Kohala Mission	540	" "	1890	7:30 a.m.	Daily	Daily	Sta. 22; Bonds Residence; Iole
176	Kohala (Maulili)	960	" "	1909	6:30 a.m.	Daily	Daily	Kohala Mauka; Maulili; Kohala 3 Weir Sta. 11
176A	Kehena Reservoir	2500	Kohala Ditch Co.	1942	6 a.m. & 4 p.m.	Daily	Daily	
177	Sta. 8 (Kohala Sug.)	125	Kohala Sugar	1941	6:30 a.m.	Daily		Kohala Old R.R. Station
177A	Makapala (A & F)	1600	Terr. Div. of For.	1925	7-8 a.m.	Daily		
178	Headquarters (Kahua R.)	3200	Kahua Ranch	1931	6-8 a.m.	After rain		Kahua 2; House

HAWAII RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
178A	Sta. 21 (Kohala Sug.)	1850	Kohala Sugar	1946	8:30 a.m.	After rain Weekly		Iole 10
178B	Twin Reservoir	1850	Kohala Ditch Co.	1940		Weekly		
178C	Kalope	3400	Kahua Ranch	1937	9-11 a.m.	After rain		Kawaihoe 2
179	Niulii	75	Kohala Sugar	1884	7:30 a.m.	Daily	Daily	Sta. 13; Niulii Office, Niulii
179A	Kohala	310	Kohala Sugar	1889	7 a.m.	Daily	Daily	Sta. 7; Kohala Mill
180A	Sta. 18 (Kohala Sug.)	425	Kohala Sugar	1933	7 a.m.	Daily		Halawa Mill
181	Makapala (Kohala Sugar)	1600	Kohala Sugar	1933	7 a.m.	Daily	Daily	Sta. 20; Makapala Nursery
181A	Honokane	850	Kohala Ditch	1905	6 a.m. & 4 p.m.	Daily	Daily and Monthly	
181B	Kehena	3800	Kohala Ditch	1912	Afternoon	Daily	Daily	Puu Laulau
182	Sta. 12 (Kohala Sug.)	1050	Kohala Sugar	1942	7 a.m.	Daily		Niulii 15; Waiapuka Wiu
182A	Awini	1900	Kohala Ditch Co.	1905	6 a.m. & 4 p.m.	Daily	Daily	
183	Sta. 19 (Kohala Sug.)	750	Kohala Sugar	1933	7:30 a.m.	Daily		Niulii Mauka
183A	Puu Ahia	4000	Kahua Ranch	1937	9-11 a.m.	After rain		Ahia; Kawaihae 1
183B	East Honokane	4200	Kohala Ditch	1925		Weekly or Monthly	Monthly	
184	Kawaihae Uka	2700	Parker Ranch	1936		After rain		
184A	Kaukini	2000	Kohala Ditch Co.	1924	6 a.m. & 4 p.m.	Daily	Daily	
185	Kawainui (Upper)	4080	Haw. Ir. Co.	1907	6-7 a.m.	Daily	Daily	*Will stop July 31, 1948 Record goes to Parker Ranch also
185A	Kaimu	2200	U.S.G.S.	1939		Random		
187A	Waimanu	3500	U.S.G.S.	1939		Random		
190	Alakahi (Upper)	3875	Haw. Ir. Co.	1913	6-7 a.m.	Daily	Daily	*Will stop July 31, 1948 Record goes to Parker Ranch also
192	Waimea	2700	Luis F. Pinho	1891	Afternoon	Daily	Daily	Central; record to Parker Ranch
192A	Puu Kapu	2850	Terr. Div. of For.	1934		Monthly	Monthly	

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
192B	Office (Parker R.)	2850	Parker Ranch	1909		Daily		
193	Kawainui (lower)	1050	Haw. Ir. Co.	1910	6-6:30 a.m.	Daily	Daily	
194	Alakahi (lower)	1050	Haw. Ir. Co.	1910	6-7 a.m.	Daily	Daily	
194A	Waikoloa	3000	U.S.G.S.	1947		Random		
195	Koiawe (Upper)	3350	Haw. Ir. Co.	1912		Weekly	Monthly	*Will stop July 31, 1948
196	Koiawe (lower)	1000	Haw. Ir. Co.	1910		Weekly	Monthly	
197	Waima (lower)	980	Haw. Ir. Co.	1913		Weekly	Monthly	
198	Muliwai	1200	Terr. Div. of For.	1931		Quarterly		
199	Kukuihaele (HIC)	950	Haw. Ir. Co.	1909	6-7 a.m.	Daily	Daily	Main Wiu Kukuihaele
200	Puu Alala	2800	Haw. Ir. Co.	1915		Daily	Daily	*Will stop July 31, 1948
201	Puu Kapu Res. 3	2820	Haw. Ir. Co.	1921	6-7 a.m.	Daily	Daily	*Will stop July 31, 1948
202	Lalakea	1955	Honokaa Sugar	1910		Weekly		
203	Second Gate	2750	Parker Ranch	1919		Daily		
204	Puu Kikonii	3200	Parker Ranch	1920		Daily		New Dairy
205	Kukuihaele Village	750	Honokaa Sugar	1890	6-6:30 a.m.	Daily		
206	Kukuihaele Mill	275	Honokaa Sugar	1891	6-7 a.m.	Daily	Daily	
207	Ahualoa Homesteads	2550	Haw. Ir. Co.	1912	6-7 a.m.	Daily	Daily	
210	Kapulena	850	Honokaa Sugar	1890	6-6:30 a.m.	Daily		
211	Reservoir 13 (H.S.)	1480	Honokaa Sugar	1910		Weekly		
212	Kamaka Gate	2500	Parker Ranch	1910		Daily		First Gate
213	Kawela	380	Honokaa Sugar	1890		Weekly		
214	Honokaa	460	Haw. Ir. Co.	1890	6-7 a.m.	Daily	Daily	Honokaa Office
215	Honokaa Village	1100	Honokaa Sugar	1910	6-7 a.m.	Daily	Daily	
215A	Honokaa-Central	1000	Telephone Co.			Daily		
216	Paauhau (Parker R.)	1750	Parker Ranch	1909		Daily		Paauhau Camp
217	Paauhau (Paauhau Sug.)	400	Paauhau Sugar	1915	8 a.m.	Daily	Daily	Paauhau Mill
218	Hamakua Mill	230	Hamakua Mill Co.	1900	6:30 a.m.	After rain		
220	Paauhau Mauka	1100	Paauhau Sugar	1917	8 a.m.	Daily		Manager's house
221	Paauilo	750	Hamakua Mill	1925	4 p.m.	After rain	Daily	
222	Kukaiau	800	Hamakua Mill Co.	1900	5-6 a.m.	After rain	Daily	
223	Ookala	450	Kaiwiki Sugar Co.	1891	6-7 a.m.	Daily	Daily	Office

HAWAII RAIN GAGES
(Arranged alphabetically)

No.	Name of Station
207	Ahualoa Homesteads
75	Ahua Umi
58	Ainahou
58A	Ainahou 2
38	Ainapo
194	Alakahi (lower)
190	Alakahi (upper)
20	Alili Tunnel
182A	Awini
147	Beach
145	Ditchman's Stable
183B	East Honokane
142	Hakalau
135	Hakalau (mauka)
52	Halemaumau
117	Halepiula
70A	Halepiula Shed
111	Halepohaku
218	Hamakua Mill
112	Hanaipoe
31	Hapuu
168	Hawi
178	Headquarters (Kahua R.)
86A	Hilo
87	Hilo Airport
90	Hilo Sugar Co.
94	Hilo Tree Nursery
70	Holualoa (A & F)
68	Holualoa Beach
70C	Holualoa (Twigg-Smith)
27	Honaunau
137	Honohina
159A	Honoipu
214	Honokaa
215	Honokaa-Central
215	Honokaa Village
181A	Honokane
136	Honomu
143	Honomu (makai)
138	Honomu (mauka)
15	Honuapo
71	Honuaula
114	Hope-A
125	Hopuwai
72	Hualalai
92A	Huehue
121	Iolehaehae Tanks
123	Kaala
12	Kaalaiki
70B	Kaalapuali
29	Kaawaloa
69	Kahaluu Beach
69B	Kaholu
4A	Kahuku Ranch House
68B	Kailua (Kona E.S.)
68A	Kailua (Puu Waawaa)
185A	Kaimu
73B	Kainaliu
1	Ka Lae
80	Kalaieha
178C	Kalope
67	Kamaile
212	Kamaka (First) Gate
4	Kamaoa
5	Kamaoa (Ranch House)
74	Kanahaha
36	Kapapala (Ranch)
93	Kapoho
66	Kapoho mauka
210	Kapulena
184A	Kaukini
148	Kawaihae
184	Kawaihae Uka
193	Kawainui (lower)
185	Kawainui (upper)
213	Kawela
91A	Keaau
22	Keaiwa
97	Keamoku
124	Keanakolu
51A	Keauhou
73A	Keauhou 2
181B	Kehena
176A	Kehena Reservoir
45	Kekekaniho
105	Kemole 1
104	Kemole 2
132	Kihalani
7	Kiolakaa
6	Kiolakaa (A & F)
179A	Kohala
176	Kohala (Maulili)
175A	Kohala Mission
196	Koiawe (lower)
195	Koiawe (upper)
162A	Kokoiki
30	Komakawai
222	Kukaiau
199	Kukuihaele (HIC)
206	Kukuihaele Mill
205	Kukuihaele Village
79	Kulani (camp)
81	Kulani Ditch
78	Kulani (School site)
122	Laaumai
202	Lalakea
68C	Lanihau
45A	Lava Flow
159	Mahukona
103	Makahalau
134	Makahanaloa 2 (mauka)
177A	Makapala (A & F)
181	Makapala (Kohala Sugar)
11	Makino
2	Manuka
126	Maulua
43A	Maunaiu
147A	Middle Pen
17	Moaula Reservoir
18	Moaula Station
16	Moaula Tunnel
10	Mountain House
91	Mountain View
198	Muliwai
14	Naalehu
28	Napoopoo
128	Nauhi Gulch
179	Niulii
52A	Observatory
192B	Office (P.R.)
44	Ohaikea
54A	Ohialani Dairy
69A	Ohia Liilii
92	Olaa
106	Old Dairy
223	Ookala
130	Ookala (1750)
216	Paauhau (P.R.)
217	Paauhau (Paauhau Sugar)
220	Paauhau mauka
221	Paauilo
21	Pahala
2A	Pahipa Gage
65	Pahoa
25	Pahoehoe
37	Pakao
116	Papa
133	Papaaloa
144A	Papaikou
140A	Papaikou (mauka)
77	Papaloa
140	Pepeekeo (A & F)
144	Pepeekeo
141	Pepeekeo (mauka)
89	Piihonua

HAWAII RAIN GAGES—Continued

(Arranged alphabetically)

No.	Name of Station
107	Pohakuloa
125A	Puakala
161	Puakea
95A	Puako
9	Punaluu Kahawai
183A	Puu Ahia
200	Puu Alala
93A	Puuanahulu
102	Puuanuanu
148A	Puu Hanae
96	Puuhinei
95	Puuhinei 2
170	Puuhue
192A	Puu Kapu
201	Puu Kapu Reservoir 3
120	Puu Kihe
204	Puu Kikoni
102A	Puu Laau
73	Puu Lehua
127	Puu Loa
113	Puu Mali
110	Puunoho
167	Puuokumau
82	Puu Oo
94A	Puu Waawaa
211	Reservoir 13 (H.S.)
88A	Kaumana
203	Second Gate
3	South Point Corral
162	Sta. 2 (Kohala Sugar)
160	Sta. 3 " "
165	Sta. 4 " "
171	Sta. 5 " "
174	Sta. 6 " "
177	Sta. 8 " "
164	Sta. 9 " "
182	Sta. 12 " "
166	Sta. 14 " "
163	Sta. 15 " "
173	Sta. 16 " "
172	Sta. 17 " "
180A	Sta. 18 " "
183	Sta. 19 " "
178A	Sta. 21 " "
115	Stone Corral
26	Takashiba
38A	Truck Trail
178B	Twin Reservoir
118	Umikoa
160B	Upolu Airport
54	Volcano Observatory
88	Waiakea
87A	Waiakea Mill
89A	Waiakea Mill Camp 6
71A	Waihou 1
100	Waikii
194A	Waikoloa
197	Waima (lower)
192	Waimea
187A	Waimanu
13	Waiubata
51	Wentworth
35	Wood Valley Tunnel
3B	1 Watershed
3A	3 Makai Watershed
2B	3 Mauka Watershed

21° 00'

50'

40'

30'

20'

10'

156° 00'

BALDWIN PACKERS LTD.

LAHAINA

WAILUKU

KAHULUI

PAIA

KEANAE

KIHEI

HALEAKALA

HANA

KIPAHULU

WAILUKU SUGAR CO.

HONOLUA

HONOLUA ASS'N.

MAUI PINE

LIBBY

M.P.

P.M.

1000

2000

4000

6000

8000

MILES

0 1 2 3 4

EXPLANATION OF SYMBOLS

- A single circle is a gage read daily or after each rain
- A double circle is a recording rain gage
- A triangle is a gage read weekly, monthly, or intermittently
- The longer dashes are field boundaries or property lines
- The series of dots are the primary roads

COA S JC PRI & HSPA EXP. STA. MAR. 1948

MAUI RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
248	Kanahena	800	Ulupalakua Ranch	1925	Mon. & Fri.	Semiweekly		
250	Ulupalakua	1916	" "	1923		After rain		
252	Auwahi	2000	" "	1925	Mon. & Fri.	Semiweekly		Auwahi II Paddock
254	Kahikinui	1400	" "	1925	" " "	"		
256	Waiopai	100	Haleakala Ranch	1900	" " "	After rain		
258	Kipahulu	220	Ulupalakua Ranch	1898		Daily	Daily	
260	Keawakapu	350	Haleakala Ranch	1948		After rain		
261	Puu Loa	1100	Ulupalakua Ranch	1925	Mon. & Fri.	Semiweekly		
262	Kamaole Pen	1700	Haleakala Ranch	1946		After rain		
263	Kamaole Makai	2200	" "	1936		" "		
264	Waihou	3250	Ulupalakua Ranch	1930		Weekly		
265	Kamaole Mauka	2800	Haleakala Ranch	1936	6-7 a.m.	Daily		
267	Kula Sanitorium	3000	Kula Sanit.	1916		Daily	Daily	
280	Kahalawe	1100	U.S.G.S.	1930		Irregular		
296	Olowalu	6	Pioneer Mill	1891	7 a.m.	After rain	Daily	#16 Olowalu Mill
301	Ukumehame	70	" "	1929	7 a.m.	Daily	Daily	Fld. 27-28
307	Reservoir #9 (Wailuku Sugar)	300	Wailuku Sugar	1947	6 a.m.	Daily	Daily	This gage used to be at Res. #8
310	Camp 7 (H.C. & S.)	80	Hawaiian Com. & Sugar	1900	6-7 a.m.	Daily		
311	Kihei	60	" " "	1929	6-7 a.m.	Daily	Daily	Fld. 19 (H.C. & S.)
312	Puunene Airport	130	C.A.A.			Daily		
313	Camp K-3	20	Hawaiian Com. & Sugar	1943	6-7 a.m.	Daily	Daily	Kihei
314	Station 8 (Maui Ag.)	600	Maui Agric. Co.	1940	7-11 a.m.	Weekly		Fld. 87
315	Pulehu	450	" " "	1925	5-6 a.m.	After rain	Daily	
316	Station 6 (Maui Ag.)	650	" " "	1940		Weekly		Fld. 85
317	Station 7 (Maui Ag.)	850	" " "	1940	6-8 a.m.	After rain		
318	Waiakoa	1100	Haleakala Ranch	1937		" "		Location may be off
320	Gage 22 (Libby)	1250	Libby	1945	7-8 a.m.	Daily		Old Fld. 244, new Fld. 230. Record begins 1927-1930 but stopped during the war.
321	Puu Ka Kai	1650	Haleakala Ranch	1946		After rain		

MAUI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
322	Erehwon Makai	2200	Ulupalakua Ranch	1930	Sat.	Weekly		
323	Garcia	2500	Haleakala Ranch	1946		After rain		
324	Erehwon Mauka	3750	Ulupalakua Ranch	1930		" "		This is *not* the Erehwon Mauka sent to W.B.—See Sta. 328
325	Fld. 50 (Maui Pine)	1770	Maui Pine Co.	1934	6-7 a.m.	Daily		Kula
326	Nolle-Smith	3300	Mrs. Nolle-Smith	1948	7 a.m.	Daily		
327	Fld. X (Maui Pine)	2600	Maui Pine Co.	1934	6-7 a.m.	After rain		
328	Kula (Erehwon)	4000	Zabrisky, Isobe	1890	Afternoon	Daily	Daily	Called "Erehwon Mauka" by Ulupalakua Ranch
329	Olinda Nursery	3800	Bd. of Ag. & Forestry		7 a.m.	Daily		
330	Alelani	3500	Haleakala Ranch	1936	6-7 a.m.	Daily		Gomi or Old Corn Lands
331	Mountain	5500	" "	1947		Monthly		Location approximate
332	Olinda	4140	Makawao Water Co.	1910-1913	7-8 a.m.	After rain		Olinda Reservoir, Olinda #1
				1913-1938		Except Sat.		
				1943-		& Sun.		
333	Ukulele	5200	Haleakala Ranch	1905		Monthly		
334	Olinda #2	4230	Makawao Water Co.	1938		"		1:10 gage
335	Intake	5000	Hal. R. & EMI	1934		Monthly		Owned and read by H.R., but records to EMI. Waiakamoi Gulch. Overflows frequently at 32"-34"; note also applies to Sta. 340
336	Waiakamoi Gulch	4250	Makawao Water Co.	1910		Irregularly	Monthly	
338	Haleakala Ranger Sta.	7030	Ranger, U. S. Park Ser.	1939		Daily	Daily	
340	Waiakamoi (5800)	5800	Hal. Ranch & EMI	1933		Monthly		Same remarks as for #335
341	Honomanu Gulch	6250	Hal. R. & EMI	1933		Monthly	Monthly	Same remarks as for #340
342	Puohakamoa	4300	Makawao Water Co.			Irregularly		1:10 gage; Haipuena
343	Puohakamoa #2	2930	(EMI) (MA)	1923		"	Monthly	Puohakamoa (Mauka)
344	Honomanu Mauka	3100	" "	1925		"	Monthly	
346	Keanae	1000	East Maui Irr. Co.	1904		Daily	Daily	

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
348	Wailua Iki	2500	East Maui Irr. Co.	1937		Irregularly		West Wailua Iki
350	Paakea	1200	" " " "	1904		Daily	Daily	Paakea Gulch, Nahikii
351	Kuhiwa Gulch	3100	" " " "	1933	Semi-annual			Location possibly off
352	Puu Paki	3170	" " " "			Irregularly		
354	Hana	250	Hana Ranch Co.	1907		Daily	Daily	
360	#23 I-3 (Pioneer Mill)	200	Pioneer Mill Co.	1933	7-8 a.m.	After rain		
361	Lahaina	50	" " "	1913	7:30 a.m.	Daily	Daily	Lahaina Main Office
362	#21 Frank Lua	75	" " "	1939	7-8 a.m.	After rain		
363	#22 Fld. F-1 (Pioneer Mill)	900	" " "	1933	7-8 a.m.	" "		
364	Wahikuli	580	" " "	1912	7 a.m.	" "	Daily	Crater Village #14; Wahikuli Village
365	#33 Fld. MD-1 (Pio. Mill)	75	" " "	1941	7-8 a.m.	" "		
366	#18 Fld. LB-2 (Pio. Mill)	550	" " "	1927	7-8 a.m.	" "		
367	#20 Joe Lua	275	" " "	1931	7-8 a.m.	" "		
370	#32 Fld. E-1 (Pio. Mill)	1600	" " "	1941	7-8 a.m.	" "		
371	#19 Fld. LB-7 (Pio. Mill)	525	" " "	1931	7-8 a.m.	" "		
372	Hirai Camp	250	" " "	1918	7 a.m.	" "	Daily	Launiupoko Village; #15
373	#17 Fld. LA-5 (Pio. Mill)	975	" " "	1927	7-8 a.m.	" "		
374	Kahoma Intake	2000	" " "	1912	7 a.m.	Daily	Daily	Kahoma
375	Kauaula Intake	1550	" " "	1912	2 p.m.	"	Daily	Kanaula
376	Launiupoko Intake	1300	" " "	1912	2 p.m.	After rain	Daily	Launiupoko
377	Olowalu Gulch	700	" " "	1911	8 a.m.	Monthly	Monthly	Olowalu
380	Kukui	5800	Baldwin Packers	1928		"	Monthly	Puu Kukui—Pioneer used to read
386	Wailuku Stables	250	Wailuku Sugar Co.	1932	6 a.m.	Daily		
387	Hopoi Camp	400	" " "	1933	6 a.m.	"		Hopoi Reservoir
390	Waikapu	470	" " "	1933	6 a.m.	"	Daily	Waikapu Stables
391	Hayashi Camp	340	" " "	1932	6 a.m.	"		
392	Wailuku	200	Rev. Fischer	1901		Daily	Daily	Boys School
393	Fld. H (H.C. & S.)	130	Ha. Com. & Sugar Co.	1929	6-7 a.m.	Daily		
394	Camp 6 (H.C. & S.)	110	" " " " "	1929	" " "			
395	Dairy (H.C. & S.)	20	" " " " "	1943	" " "			Puunene Dairy

MAUI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
396	Puunene	70	Haw. Com. & Sugar Co.	1899	6-7 a.m.	Daily	Daily	
397	Fld. D (H.C. & S.)	170	" " " " "	1929	" " "	"		
400	Spreckelsville	60	" " " " "	1899	6-7 a.m.	Daily	Daily	Camp 1
401	Fld. 3 (H.C. & S.)	370	" " " " "	1929	" " "	Daily		
402	Camp 10 (H.C. & S.)	370	" " " " "	1900	" " "	Daily		
403	Fld. A (H.C. & S.)	130	" " " " "	1929	6-7 a.m.	Daily		
404	Camp 11 (H.C. & S.)	350	" " " " "	1928	" " "	"		
405	No. 3 (Maui Ag.)	120	Maui Agr. Co.	1940	7-11 a.m.	Weekly		Fld. 67
406	Paia	120	" " "	1909	5-6 a.m.	After rain	Daily	
407	Fld. 76 (Maui Ag.)	300	" " "	1946		Weekly		
410	Keahua	520	" " "	1909	5-6 a.m.	After rain	Daily	
411	No. 5 (Maui Ag.)	650	" " "	1940		Weekly		Fld. 23
412	Gage 24 (Libby)	900	Libby	1947	7-8 a.m.	Daily		Rice Land
413	Kaheka	370	Maui Ag. Co.	1946	5-6 a.m.	After rain		
414	Kailua (Camp)	700	" " "	1930	6-8 a.m.	After rain		
415	No. 4 (Maui Ag.)	670	" " "	1940		Weekly		Fld. 77
416	No. 1 (Maui Ag.)	290	" " "	1940		Weekly		Fld. 8
417	No. 2 (Maui Ag.)	710	" " "	1940		Weekly		Fld. 53
419	No. 9 (Maui Ag.)	1070	" " "	1928	6-8 a.m.	After rain		Fld. 92
420	Gage 25 (Libby)	1150	Libby	1946	7-8 a.m.	Daily		Old Fld. 245, new Fld. 233. Began 1927-1930
421	Fld. 206 (Maui Pine)	700	Maui Pine Co.	1948		Weekly		
422	Paholei	920	Maui Ag. Co.	1923	5-6 a.m.	After rain		
423	Station (Maui Pine)	1070	Maui Pine Co.	1934	5-7 a.m.	Daily		Exp't Station
424	Fld. 22 (Maui Pine)	1400	Maui Pine Co.	1939	1-3 p.m.	Weekly		
425	Fld. 218 (Maui Pine)	1200	" " "	1939		Weekly		
426	Gage 21 (Libby)	1620	Libby	1926	7-8 a.m.	Daily		Old Fld., new Fld. 232
427	Fld. 26 (Maui Pine)	1800	Maui Pine Co.	1934	8-9 a.m.	After rain		Pukalani, Recorder
430	Fld. 210 (Maui Pine)	1100	Maui Pine Co.	1934	1-3 p.m.	After rain		
431	Gage 23 (Libby)	1520	Libby	1945	7-8 a.m.	Daily		Old Fld. 244, New Fld. 239. Began 1927-1930
432	Haleakala Ranch	1900	Haleakala Ranch	1892	6-7 a.m.	Daily	Daily	Kapalaea

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
433	Piholo	1900	Maui Pine Co.	1934	6-7 a.m.	After rain		
434	Haleakala Branch	2160	U. of H. Exp. Sta.	1921		After rain	Daily	
435	Opana Gulch	1320	East Maui Irrig. Co.	1937		Irregularly		Opana
436	Kailiili	2400	(EMI & MA)	1925		Daily	Daily	
440	Opana	3100	" " "	1923		Monthly	Monthly	Opana Mauka
441	Hoolawa	670	EMI & USGS	1936		Quarterly		Lupi Road
442	Lupi	1100	East Maui Irrig. Co.	1897		Weekly	Monthly	Lupi Camp
443	Kailua Mauka	3100	(EMI & MA)	1923		Monthly	Monthly	
444	Waipio	700	East Maui Irrig. Co.	1938		Irregularly		
445	Kailua Mauka (USGS)	1240	EMI & USGS	1936		Weekly		Kailua Gulch. USGS reads it quarterly
446	Kailua	700	East Maui Irrig. Co.	1904		Daily	Daily	
447	Punaluu	700	East Maui Irrig. Co.	1906		Weekly	Monthly	
449	Waiakamoi	1200	" " " "	1906		Daily	Daily	Alo Stream
450	Honomanu	1250	" " " "	1904		Weekly	Monthly	Honomanu Lower
451	Honomanu (USGS)	1790	EMI & USGS	1937		Irregularly		USGS reads gage
453	Kaanapali	25	Pioneer Mill Co.	1912	8 a.m.	Daily	Daily	Kaanapali Landing
454	#27 Fld. D-7 (Pio. Mill)	50	" " "	1933	7-8 a.m.	After rain		
455	#26 Fld. D-4 (Pio. Mill)	50	" " "	1930	7-8 a.m.	After rain		
456	#25 Fld. C-7 (Pio. Mill)	325	" " "	1927	7-8 a.m.	" "		
457	Puukolii	360	Pioneer Mill Co.	1912	8:30 a.m.	Daily	Daily	
458	#12 Kahana Camp	50	" " "	1928	7-8 a.m.	After rain		
460	#28 Honokowai Lua	300	" " "	1938	7-8 a.m.	" "		
461	#31 Fld. C-1 (Pio. Mill)	325	" " "	1941	7-8 a.m.	" "		
462	#13 Pedio Camp	450	" " "	1929	7-8 a.m.	" "		
463	#30 Fld. B-8 (Pio. Mill)	675	" " "	1941	" " "	" "		
464	#24 Fld. B-2 (Pio. Mill)	825	" " "	1933	" " "	" "		
465	Fld. 104 (Baldwin Packers)	710	Baldwin Packers	1935		Daily		
466	Mahinahina (Pio. Mill)	750	Pioneer Mill Co.	1914	7 a.m.	Daily	Daily	Mahinahina Weir
467	#27 Fld. A-3 (Pio. Mill)	1100	" " "	1941	7-8 a.m.	After rain		
470	Fld. 33 (Baldwin P.)	400	Baldwin Packers	1937	6-7 a.m.	Daily		Russell's House
471	Fld. 28 (Baldwin P.)	750	" "	1944		Monthly		

MAUI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
472	Puu Kukui Makai	2000	Pioneer Mill Co.	1929		Monthly	Monthly	
473	Mahana	1500	Baldwin Packers	1896		Monthly	Monthly	
474	Fld. 44 Mauka (Baldwin P.)	1260	" "			Monthly		
475	Mokupea	1900	" "	1899		Monthly	Monthly	
476	Mahinahina Weir (Baldwin Packers)	1720	Baldwin Packers	1912	8 a.m.	Daily		Same as Pioneer's Honokowai
476	Honokowai Intake	1720	Pioneer Mill Co.	1912	8 a.m.	Daily	Daily	Same as Packer's Mahinahina Weir
477	Haelaau	2980	Baldwin Packers	1933		Monthly	Monthly	
480	Honokohau	800	" "	1907		Monthly	Monthly	7 mo. without record in 1929
481	Nakalalua	4500	Pioneer Mill Co.	1935		Monthly	Monthly	
482	Waihee Valley	300	Wailuku Sugar Co.	1913	6 a.m.	Daily	Daily	
483	Waihee	100	" " "	1913	6 a.m.	"	"	Waihee Stables
484	Waiehu Camp	320	" " "	1913	6 a.m.	"	"	Fld. 25 Reservoir
485	Hamakuapoko	310	Maui Agr. Co.	1884	5-6 a.m.	After rain	Daily	
486	Fld. 202 (Maui Pine)	300	Maui Pine Co.	1938	1-3 p.m.	" "		
487	Field C (Maui Pine)	300	" " "	1945	" " "	" "		Field B-C
488	Haiku (A & F)	450	Bd. Ag. & For.		7 a.m.	Daily		
490	Haiku	470	Libby	1921	7-8 a.m.	Daily	Daily	Pauwela Cannery; 16-Haiku
491	Gage 26 (Libby)	550	Libby	1947	5-6 a.m.	Daily		Opana, Fld. 317
492	Kapalaalaea	450	E.M.I.	1936	Quarterly or random			
493	Honokahua	500	Baldwin Packers	1920		Daily	Daily	Fld. 38
494	Honolua	100	" "	1894		Monthly	Monthly	Honolua Makai; Fld. 49
495	Fld. 64 (Baldwin Packers)	750	" "	1940	8-11 a.m.	Weekly		
496	Fld. 62 (Baldwin Packers)	500	" "	1937		Weekly		
497	Nakalele	300	" "	1937		Weekly	Monthly	Field 60

MAUI RAIN GAGES

(Arranged alphabetically)

No.	Name of Station
330	Alelani
252	Auwahi
394	Camp 6 (HC&S)
310	Camp 7 (HC&S)
402	Camp 10 (HC&S)
404	Camp 11 (HC&S)
313	Camp K-3
395	Dairy (HC&S)
322	Erehwon Makai
324	Erehwon Mauka
403	Field A (HC&S)
467	Field A-3 (PM)
464	Field B-2 (PM)
463	Field B-8 (PM)
487	Field C (MP)
461	Field C-1 (PM)
456	Field C-7 (PM)
397	Field D (HC&S)
455	Field D-4 (PM)
454	Field D-7 (PM)
370	Field E-1 (PM)
363	Field F-1 (PM)
393	Field H (HC&S)
360	Field I-3 (PM)
373	Field LA-5 (PM)
366	Field LB-2 (PM)
371	Field LB-7 (PM)
365	Field MD-1 (PM)
327	Field X (MP)
401	Field 3 (HC&S)
424	Field 22 (MP)
427	Field 26 (Pukalani) (MP)
471	Field 28 (BP)
470	Field 33 (BP)
474	Field 44 Mauka (BP)
325	Field 50 (MP)
496	Field 62 (BP)
495	Field 64 (BP)
407	Field 76 (MA)
465	Field 104 (BP)
486	Field 202 (MP)
421	Field 206 (MP)
430	Field 210 (MP)
425	Field 218 (MP)
362	Frank Lua
426	Gage 21 (Libby)
320	Gage 22 (Libby)
431	Gage 23 (Libby)
412	Gage 24 (Libby)
420	Gage 25 (Libby)
491	Gage 26 (Libby)
323	Garcia
477	Haelaau
488	Haiku (A&F) (Bd. For. & Ag.)
490	Haiku (Libby)
434	Haleakala Branch
432	Haleakala Ranch
338	Haleakala Ranger Station
485	Hamakuapoko
354	Hana
391	Hayashi Camp
372	Hirai Camp
493	Honokahua
480	Honokohau
476	Honokowai (Intake) (PM)
460	Honokowai Lua
494	Honolua
451	Honomanu (USGS)
341	Honomanu Gulch
450	Honomanu
344	Honomanu Mauka
441	Hoolawa
387	Hopai Camp
335	Intake (Waiakamoi Gulch)
367	Joe Lua
453	Kaanapali
280	Kahalawe
458	Kahana Camp
413	Kaheka
254	Kahikinui
374	Kahoma Intake
436	Kailiili
414	Kailua (Camp)
446	Kailua
445	Kailua Mauka (USGS)
443	Kailua Mauka (EMI)
263	Kamaole Makai
265	Kamaole Mauka
262	Kamaole Pen
248	Kanahena
492	Kapalaalaea
375	Kauaula Intake
410	Keahua
346	Keanae
260	Keawakapu
311	Kihei
258	Kipohulu
351	Kuhiwa Gulch
380	Kikui
328	Kula (Erehwon)
267	Kula Sanitorium
361	Lahaina
376	Launiupoko Intake
442	Lupi
473	Mahana
466	Mahinahina
476	Mahinahina Weir
475	Mokupea
331	Mountain
481	Nakalalua
497	Nakalele
326	Nolle-Smith
416	No. 1, Field 8 (MA)
417	No. 2, Field 53 (MA)
405	No. 3, Field 67 (MA)
415	No. 4, Field 77 (MA)
411	No. 5, Field 23 (MA)
419	No. 9, Field 92 (MA)
332	Olinda
334	Olinda 2
329	Olinda Nursery
377	Olowalu Gulch
296	Olowalu
435	Opana Gulch
440	Opana
350	Paakea
422	Paholei
406	Paia
462	Pedio Camp
433	Piholo
315	Pulehu
447	Punaluu
342	Puohakamoa
343	Puohakamoa #2
321	Puu Ka Kai
457	Puukolii
472	Puu Kukui Makai
261	Puu Loa
312	Puunene Airport
396	Puunene
352	Puu Paki
307	Reservoir 9 (WS)
400	Spreckelsville
423	Station (MP)
316	Sta. 6 (MA)
317	Sta. 7 (MA)
314	Sta. 8 (MA)
333	Ukulele
301	Ukumehame
250	Ulupalakua
364	Wahikuli
318	Waiakoa
484	Waiehu Camp
483	Waihee

MAUI RAIN GAGES—Continued
(Arranged alphabetically)

No.	Name of Station	No.	Name of Station	No.	Name of Station
482	Waihee Valley	336	Waiakamoi Gulch	386	Wailuku Stables
264	Waihou		(Mack. W)	256	Waiopai
449	Waikamoi	390	Waikapu	444	Waipio
340	Waiakamoi (5800)	348	Wailua Iki		
	(HR&EMI)	392	Wailuku		

MOLOKAI RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
500	Kamakaipo	40	Molokai Ranch	1933		After rain		
500A	Pokohala	350	" "	1928		" "		
501	Gage 31 (Libby)	275	Libby	1947	7-8 a.m.	" "		Kaupo
502	Gage 30 (Libby)	250	"	1946	" " "	" "		West of Fld. 21; Fld. 46-2
503	Gage 22 (Libby)	500	"	1927	" " "	" "		Fld. 29
504	Gage 32 (Libby)	440	"	1947	" " "	" "		SW of Fld. 30; Puaukina
505	Gage 14 (Libby)	450	"	1924	" " "	" "		Field 21
511	Maunaloa Office	1040	"	1924	" " "	" "	Daily	Maunaloa Village; Gage 4
513	Gage 5 (Libby)	520	"	1947	" " "	" "		Field 9
514	Field 12 (Libby)	1220	"	1942	Recorder			Recorder called Moanaloa
517	Gage 27 (Libby)	700	"	1931	7-8 a.m.	After rain		Field 3
518	Gage 33 (Libby)	1350	"	1947	" " "	" "		Field 5
519	Kaana	1200	Molokai Ranch	1947		" "		
520	Mahana	650	" "	1933		" "		
521	Pipika	350	Cal. Pack. Corp.	1940	8-12 a.m.	Monthly and after rain		
522	Gage 35 (Libby)	400	Libby	1947	8-9 a.m.	After rain		Field 408, Lot 179
523	Gage 26 (Libby)	470	"	1932	" " "	" "		Field 407, Lot 186
524	Homestead Field	450	Hawaiian Airlines			Daily		
525	Green Flat	300	Cal. Pack. Corp.	1943	8-12 a.m.	Monthly and after rain		
526	Gage 315 (CPC)	370	" " "	1927	" " "	Monthly and after rain		
527	Hoolehua (Gage 24 Libby)	600	Libby	1932	8-9 a.m.	After rain		Hoolehua Camp, Lot 69
528	Gage 322 (CPC)	570	Cal. Pack. Corp.	1927	8-12 a.m.	Recorder		Recorder called Kanaio
529	Gage 325 (CPC)	320	" " "	1929	" " "	Monthly and after rain		
530	Gage 302 (CPC)	750	" " "	1933	" " "	Monthly and after rain		
531	Gage 305 (CPC)	900	" " "	1940	" " "	Recorder		Recorder called Kualapuu
532	Gage 312 (CPC)	500	" " "	1933	" " "	Monthly and after rain		

MOLOKAI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
533	Gage 309 (CPC)	550	Cal. Pack. Corp.	1927	8-12 a.m.	Monthly and after rain		
534	Kualapuu (CPC)	870	" " "	1927	7 a.m.	Daily	Daily	CPC Hdq. Off.
535	Gage 304 (CPC)	750	" " "	1929	8-12 a.m.	Monthly and after rain		
536	Kaunakakai	40	Molokai Ranch	1933		After rain		
537	Poholua	2150	" "	1930		" "		
540	Waikolu	3500	" "	1930		" "		
541	Kaweka	3750	" "	1947		" "		
542	Mapulehu	20	HSPA Quarantine Sta.			Daily	Monthly	Puleoo, Pukoo
543	Pelekuna	550	USGS	1939		Irregular		
544	Puu Lua	2800	USGS	1922		"		
550	Kepuhi	30	Molokai Ranch	1933		After rain		
551	Keonelele	550	" "	1933		" "		Keonelele Pens
552	Gage 29 (Libby)	650	Libby	1946	7-8 a.m.	" "		Field 31
554	Monomi	360	Cal. Pack. Corp.	1945	8-12 a.m.	Monthly and after rain		
555	Gage 36 (Libby)	430	Libby	1947	8-9 a.m.	After rain		Field 406, Lot 191
556	Hoolehua (CPC)	480	Cal. Pack. Corp.	1926	8-12 a.m.	Monthly and after rain	Monthly	Lot 122, Hoolehua
557	Gage 23 (Libby)	575	Libby	1932	8-9 a.m.	After rain		Field 402, Lot 51
558	Gage 34 (Libby)	600	"	1947	8-9 a.m.	" "		Field 401, Lot 21
559	Maalehua	870	Molokai Ranch	1933		" "		Maalehua Camp
560	Gage 301 (CPC)	1000	Cal. Pack. Corp.	1927	8-12 a.m.	Monthly and after rain		
561	Gage 501 (CPC)	1100	" " "	1929	" " "	Monthly and after rain		
562	Kipu	1230	" " "	1930	" " "	Recorder	Monthly	Kipu Camp (CPC)
563	Kalaupapa	50	Brother Matern	1933		Daily	Daily	

MOLOKAI RAIN GAGES

(Arranged alphabetically)

No.	Name of Station	No.	Name of Station	No.	Name of Station
514	Field 12 (Libby)	535	Gage 304 (CPC)	536	Kaunakakai
513	Gage 5 (Libby)	531	Gage 305 (CPC)	541	Kawela
505	Gage 14 (Libby)	533	Gage 309 (CPC)	551	Keonelele
503	Gage 22 (Libby)	532	Gage 312 (CPC)	550	Kepuhi
557	Gage 23 (Libby)	526	Gage 315 (CPC)	562	Kipu
523	Gage 26 (Libby)	528	Gage 322 (CPC)	534	Kualapuu (CPC)
517	Gage 27 (Libby)	529	Gage 325 (CPC)	559	Maalehua
552	Gage 29 (Libby)	561	Gage 501 (CPC)	520	Mahana
502	Gage 30 (Libby)	525	Green Flat	542	Mapulehu
501	Gage 31 (Libby)	524	Homestead Fld.	511	Maunaloa Office
504	Gage 32 (Libby)	556	Hoolehua CPC (LOT	554	Momomi
518	Gage 33 (Libby)		122)	543	Pelekuna
558	Gage 34 (Libby)	527	Hoolehua (Gage 24	521	Pipika
522	Gage 35 (Libby)		Lib)	537	Poholua
555	Gage 36 (Libby)	519	Kaana	500A	Pokohala
560	Gage 301 (CPC)	563	Kalaupapa	544	Puu Lua
530	Gage 302 (CPC)	500	Kamakaipo	540	Waikolu

LANAI RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
650	R-8 (Palikoholo)	1180	Hawaiian Pine Co.	1914		Monthly		Stearns 28
651	549	1140	" " "	1937		After rain		Stearns 21
652	R-6 (Kamoku)	1110	" " "	1924		Monthly		Stearns 14; 6 Ranch-Kamoku
653	538	1240	" " "	1935		After rain		Stearns 6
654	529	1260	" " "	1941		" "		
655	546	1270	" " "	1936		" "		Stearns 20
656	Airport	1310	C.A.A.	1947	0700-1315	Daily		
660	548	1260	Hawaiian Pine Co.	1934		After rain		Stearns 27
661	537	1460	" " "	1936	Between 6:30 & 9:00 a.m.	Recorder		Stearns 8; Standard gage read daily—nearby
662	539	1540	" " "	1934		After rain		Stearns 12
663	528	1420	" " "	1939		" "		
664	Field 5519	1360	" " "	1942	Between 6:30 & 9:00 a.m.	Recorder		Stearns 3; Standard gage read daily—nearby
665	545	1240	" " "	1936		After rain		Stearns 19
666	547	1200	" " "	1934		" "		Stearns 22
670	536	1510	" " "	1936		" "		Stearns 11
671	Lab	1600	" " "	1945	6:30 a.m.	Daily		Lanai Research Lab.
672	Lanai City	1620	" " "	1929	8:00 a.m.	Daily	Daily	
673	544	1220	" " "	1936		After rain		Stearns 26
674	541	1340	" " "	1936		" "		Stearns 18
675	542	1140	" " "	1934		" "		Stearns 23
676	R-3 (Molauea)	1140	" " "	1914		Monthly		Stearns 29; 3 Ranch Molauea
680	540	1840	" " "	1937		After rain		Stearns 15
681	543	1310	" " "	1936		" "		Stearns 25
682	550	1240	" " "	1937		" "		Stearns 24
683	555	1850	" " "	1944		" "		
684	R-4 (Lanaihāle)	3370	" " "	1924		Monthly		
685	551	2040	" " "	1939		After rain		

STA. NO PRI-HSPA	NAME USED BY HAW. PINE CO.
650	R-8
651	549
652	R-6
653	538
654	529
655	546
656	Airport
660	548
661	537
662	539
663	528
664	5519
665	545
666	547
670	536
671	Lab.
672	Lanai City
673	544
674	541
675	542
676	R-3
680	540
681	543
682	550
683	555
684	R-4
685	551
690	R-7
691	534
692	535
693	R-2
694	R-9
695	R-1
696	R-5

Miles

0 1 2 3 4

LBL & SB PINEAPPLE RESEARCH INST. & HSPA EXPER. STATION OCT, 1947

EXPLANATION OF SYMBOLS

- ○ A single circle is a gage read daily or after each rain
- ◎ A double circle is a recording rain gage
- △ A triangle is a gage read weekly, monthly, or intermittently
- ---- The longer dashes are field boundaries or property lines
- ..... The series of dots are the primary roads

ISLAND OF LANAI, T.H.

LANAI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
690	R-7 (Kanepuu)	1640	Hawaiian Pine Co.	1913		Monthly		Stearns 11 (Yearly records 1913-1918; monthly after)
691	534	1460	" " "	1936		After rain		
692	535	1550	" " "	1934		" "		Stearns 5
693	R-2 (Koele)	1740	" " "	1905	6:00 a.m.	Daily	Daily	2 Ranch-Koele; daily began 1911
694	R-9 (Mahana)	1430	" " "	1934		Monthly		Stearns 3; gage moved ¼ mi. uphill 1940—9 Ranch-Mahana
695	R-1 (Wawaeku)	750	" " "	1938		Monthly		1 Ranch—Wawaeku
696	R-5 (Keomoku)	10	" " "	1914	6:00 a.m.	Daily		5 Ranch—Keomoku

NOTE: Lanaihale read once a month; all other "R" or ranch gages are read at least once a month or whenever visited. All gages read "After rain" are read each Monday, Wednesday and Saturday and in addition, on days after rain is believed to have fallen.

LANAI RAIN GAGES
(Arranged alphabetically)

No.	Name of Station	No.	Name of Station	No.	Name of Station
656	Airport	663	528	681	543
652	(Kamoku) R-6	654	529	673	544
690	(Kanepuu) R-7	691	534	665	545
696	(Keomoku) R-5	692	535	655	546
693	(Koele) R-2	670	536	666	547
671	Laboratory	661	537	660	548
672	Lanai City	653	538	651	549
684	(Lanaihale) R-4	662	539	682	550
694	(Mahana) R-9	680	540	685	551
676	(Molauea) R-3	674	541	683	555
650	(Palikoholo) R-8	675	542	664	5519
695	(Wawaeku) R-1				

JC PRI & HSPA EXP STA. JUNE 1948

158° 00'

50'

40'

21° 30'

21° 25'

MILES

0 1 2 3 4 5

KAHUKU PLANT'N

HAW'N PINE

WAIALUA AGRIC.

W.A.

CAL. PAC.

OAHU SUGAR CO.

LIBBY

O.S.C.

EWA PLANTATION CO.

EXPLANATION OF SYMBOLS

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- A double circle is a recording rain gage
- A triangle is a gage read weekly, monthly, or intermittently
- The longer dashes are field boundaries or property lines
- The series of dots are the primary roads

OAHU RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
700	Waimanalo Stable	70	Ewa Plant. Co.	1902		After rain		West Camp
701	Barbers Point	20	U.S. Marine Corps			6 Hourly		NASBP
702	U.S. Magnetic Observ.	30	Magnetic Obs.	1900		Daily	Daily	
702A	MCAS Ewa	40	Marine Corps Air Base	1892		Daily		
703	Honolulu (W.B.A.S.)	10	U.S. Weather Bureau	1947		6 Hourly	Daily	John Rodgers Airport
704	Honolulu (W.B.O.)	10	U.S. Weather Bureau	1904		Recorder	Daily	Federal Bldg.
705	Bd. Water Supply Off.	40	Bd. Water Supply			Daily		
705A	Craigside	160	G. C. Davies	1947	7 a.m.	Daily		
706	Pacific Heights	680	Bd. Water Supply	1926		Weekly		
706A	Punchbowl	140	Rene Guillou	1948		Daily		
707	H.S.P.A. Exper. Sta.	50	H.S.P.A. Exper. Sta.	1918	8 a.m.	"	Daily	Makiki
708	Tantalus	1050	Coulter—Bd. of Wat. Sup.	1947	8:30 a.m.	"	"	
710	Nutridge	750	Macadamia Nut—B.W.S.	1927	7 a.m.	"	"	B.W.S. #14
710A	Clements	220	H. R. Clements	1948	7 a.m.	"		
711	P.R.I. (Dole St.)	70	Pineapple Research Inst.	1946	8 a.m.	Recorder	Daily	P.R.I.
712	Manoa	210	Miss Charlotte Hall	1898	6 p.m.	Daily	"	Manoa (210)
712A	Beaumont	270	J. H. Beaumont	1948	8 a.m.	"		
713	University Farm	80	Supt. of Univ. Farm	1925	3 p.m.	"	Daily	
714	Tantalus (1400)	1400	John A. Black	1947		Monthly	"	
714A	Spiegelberg	400	C. H. Spiegelberg	1947		Daily		
715	Kaimuki	280	Mr. Theo. Bush	1921		"	Daily	
716	Manoa Tunnel #2	650	Bd. of Water Supply	1927	Mid-Mid	Recorder	"	B.W.S. #12
716A	Woodlawn	270	Minnie Carter	1947	7:30 a.m.	Daily		
717	Black Point	50	F. R. Van Brocklin	1919	7:30 a.m.	"	Daily	
718	Palolo Valley	1000	Bd. Water Supply	1926		Weekly	Monthly	B.W.S. #8
720	Matsonia Drive	810	C. K. Wentworth	1938	6:30 a.m.	Daily	Daily	
720A	Collins	760	N. R. Collins	1942	7:30 a.m.	"		
721	Wilhelmina Rise	1100	Bd. Water Supply	1927	Mid-Mid	Recorder	Daily	B.W.S. #17
722	Kahala	10	Luna B. Leopold	1947	7 a.m.	Daily		
723	Wailupe	15	Hind-Clarke Dairy	1925			Daily	
724	Makapuu Point	570	U.S. Coast Guard	1907		Daily	"	
725	Mikilua	60	Waianae Co.	1928		"	"	

OAHU RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
726	D.P.D.	10	Ewa Plant. Co.	1927	6-7 a.m.	After rain		
727	Pump #10 (Ewa)	50	Ewa Plant. Co.	1911	6-7 a.m.	" "		
728	Puu Manawahua	2130	615th AC&W, APO 958, San Francisco	1948				
729	Fld. 85-86 (Cal. Pack.)	880	Calif. Packing Co.	1946	7-9 a.m.	Daily		Upper Fld. 86
729A	Fld. 86 (Cal. Pack.)	820	Calif. Packing Co.	1926	7-9 a.m.	"		Lower Fld. 86
730	Reserv. #6B (Ewa)	116	Ewa Plant. Co.	1927	6-7 a.m.	After rain		
731	Fld. 151 (Cal. Pack.)	500	Calif. Packing Co.	1928	6-9 a.m.	" "		
732	Reserv. #6 (Ewa)	90	Ewa Plant. Co.	1904	6-7 a.m.	" "		
733	Field #29 (Waipahu)	250	Oahu Sugar Co.	1920	8 a.m.	Daily		Pump #5
734	Gage #3 (Libby)	450	Libby, McNeill & Libby	1939	6-8 a.m.	After rain		Kunia B; Kupehau
735	Fld. #46 (Ewa)	60	Ewa Plant. Co.	1927	6-7 a.m.	" "		15 Switch; 15 Fld; Fld. #43
736	Reserv. #8 (Ewa)	155	Ewa Plant. Co.	1927	6-7 a.m.	" "		
737	Reserv. #9 (Ewa)	210	Ewa Plant. Co.	1924	6-7 a.m.	" "		688 4 House Camp
738	Fld. 59 (Waipahu)	640	Oahu Sugar Co.	1945	8 a.m.	Daily		
738A	Fld. 57 (Waipahu)	605	Oahu Sugar Co.	1945				
738B	Fld. 38 B (Waipahu)	530	Oahu Sugar Co.	1929				
739	Fld. 27 A (Waipahu)	360	Oahu Sugar Co.	1945	6-8 a.m.	Daily		
740	Reserv. #5 (Ewa)	120	Ewa Plant. Co.	1927	6-7 a.m.	After rain		Fld. #2A
740A	Fld. 24 (Waipahu)	500	Oahu Sugar Co.	1945				
740B	Fld. 26 (Waipahu)	280	Oahu Sugar Co.	1929				
741	Ewa	40	Ewa Plant. Co.	1904	6-7 a.m	After rain	Daily	Ewa Mill; Ewa Plantation
742	Pump #7 (Ewa)	40	Ewa Plant. Co.	1923	6-7 a.m.	" "		Reserv. #9 AB
742A	Fld. 19 (Waipahu)	370	Oahu Sugar Co.	1945				
743	Pump #2 (Ewa)	60	Ewa Plant. Co.	1927	6-7 a.m.	After rain		Reserv. #2
744	Fld. #75 (Ewa)	30	Ewa Plant. Co.	1927	6-7 a.m.	" "		Fld. #73; Windmill Road
745	Pump #4 (Waipahu)	40	Oahu Sugar Co.	1923		Daily		
745A	Fld. #15 (Waipahu)	250	Oahu Sugar Co.	1947				
746	Apokaa	70	Ewa Plant. Co.	1902	6-7 a.m.	After rain		
747	Fld. #62 (Ewa)	30	Ewa Plant. Co.	1927	6-7 a.m.	" "		Fld. #9
748	Fld. #12 (Waipahu)	290	Oahu Sugar Co.					
750	Waipahu	60	Oahu Sugar Co.	1898	8 a.m.	Daily	Daily	Office; Waipahu Office

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
751	Fld. 79.1 (Ewa)	20	Ewa Plant. Co.	1942	6-7 a.m.	After rain		Fld. 82.1
752	Waipio	50	H.S.P.A.			Recorder		
752A	Fld. 34B (Waipahu)	20	Oahu Sugar Co.	1933				
752B	Fld. 5 (Waipahu)	110	Oahu Sugar Co.	1929				
752C	Fld. 4 (Waipahu)	240	Oahu Sugar Co.					
753	Pump 6 (Waipahu)	70	Oahu Sugar Co.	1929				
754	Fld. 2 (Aiea)	250	Oahu Sugar Co.	1932	6-8 a.m.	Daily		
755	Pearl Harbor	10	U.S. Navy	1927		"	Daily	Ford Island N.A.S.
756	Waimalu	200	Oahu Sugar Co.	1902	6-8 a.m.	"	"	Waimalu Stable
757	Hickam Field	10	H.A.F. 31st Squad	1931		"	"	
758	Fleet Weather Central	40	U.S. Navy			"		
760	Fld. 41 (Aiea)	70	Oahu Sugar Co.	1947	6-8 a.m.	"		
761	Waimalu 500	500	Oahu Sugar Co.	1907			Daily	Fld. 35 (Aiea)
762	Fld. 34 (Aiea)	660	Oahu Sugar Co.	1932	6-8 a.m.	Daily		
763	Fld. 44 (Aiea)	500	Oahu Sugar Co.	1932	6-8 a.m.	"		
764	Aiea	100	Oahu Sugar Co.	1902		"	Daily	
764A	Fld. 49 (Aiea)	100	Oahu Sugar Co.	1920	6-8 a.m.	"		
765	Fld. 71 (Aiea)	60	Oahu Sugar Co.	1947	6-8 a.m.	"		
766	Aiea 500 (Fld. 65)	430	Oahu Sugar Co.	1907	6-8 a.m.	"	Daily	
767	Fld. 66 (Aiea)	140	Oahu Sugar Co.	1932		"		South Halawa
768	Red Hill	440	Ken Stewart			"		
770	Moanalua	10	Donald McIntyre	1901	8 a.m.	"	Daily	
771	Halawa North (Uka)	300	U.S.G.S.—Bd. Wat. Sup.	1929	Mid-Mid	Recorder		North Halawa, Halawa-uka BWS 24
772	Moanalua U.S.G.S.	400	U.S.G.S.—Bd. Wat. Sup.	1926	Mid-Mid	Recorder		BWS 9
773	Kapalama	50	Kamehameha Sch.	1922		Daily	Daily	
774	Kalihi USGS	500	Bd. Wat. Supply	1927		Weekly		BWS 18
774A	Nuuanu Orchid Garden	250	R. E. Warne	1948		Daily		
775	Nuuanu Reserv. 5	410	Bd. Water Supply	1930	8-10 a.m.	"	Monthly	BWS 23; Electric light
776	Kalihi Tunnel 2	650	Bd. Water Supply	1926	9-11:30	Weekly		BWS 1
777	Kalihi Reserv. Site	910	Bd. Water Supply	1927		Recorder	Monthly	BWS 19
780	Tantalus Peak	2000	Bd. Water Supply	1927		Weekly		BWS 16

OAHU RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
781	Kaneohe (Mauka)	200	Terr. Hosp. for Insane	1928		Daily	Daily	
782	Luakaha (Lower)	880	Bd. Water Supply	1890	Mid-Mid	Recorder	Daily	BWS 21
783	Nuuanu Dam 4	1050	Bd. Water Supply	1905	"	"	"	BWS 22; Upper Luakaha
784	Pauoa Flats	1800	Bd. Water Supply	1926	"	"	"	BWS 5
785	Manoa H.S.P.A.	500	H.S.P.A. Exp. Sta. & BWS	1927	4 p.m.	Daily	"	BWS 20
786	Nuuanu Pali	1150	Bd. Water Supply	1927		Weekly		BWS 13
787	Maunawili Ranch	500	U.S. Engineer Dept.			Recorder		
788	St. Stephens Seminary	500	St. Stephens Seminary	1943		Daily	Daily	
789	Konahuanui	3105	Bd. Water Supply	1926		Monthly		BWS 5
790	Kawailoa Girls Sch.	300	Kawailoa Girls Sch.			Recorder		
794	Waimanalo	20	Waimanalo Sugar	1894		Daily	Daily	
796	Makaha Kai	20	Waianae Co.	1928		"	"	
797	Kamaile Pump	50	Waianae Co.			"		
798	Waianae	10	Waianae Co.	1891		"	Daily	Waianae Mill
800	Makaha Ditch	400	Waianae Co.			"		Vegetable Garden
801	Waianae Valley	40	Waianae Co.	1930		"	Daily	Res. 6; Waianae Fld.
802	Power House	350	Waianae Co.			"		
803	Waianae (Mauka)	1500	Waianae Co.	1903		Wed. & Sat.	Monthly	Waianae Mt. 1500; Puea
804	Lualualei	110	Navy Ammun. Dep.	1935		Daily	Daily	
804A	Kolekole Pass	1640	H.S.P.A.	1933		Monthly		
805	Leilehua	920	Cal. Packing Co.	1928	6-8 a.m.	Recorder		
806	Kunia Camp	880	Cal. Packing Co.	1928	5-6 a.m.	Daily		Main Kunia Camp
807	Fld. 84 (Cal. Pack.)	810	Cal. Packing Co.	1928	5-6 a.m.	"		
808	Fld. 32 (Cal. Pack.)	875	Cal. Packing Co.	1945	6-9 a.m.	After rain		
809	Fld. 33 (Cal. Pack.)	830	Cal. Packing Co.	1945	6-9 a.m.	" "		
809A	Fld. 56 (Waipahu)	610	Oahu Sugar Co.	1945				
810	Wheeler Field	850	A.A.F.	1945		Daily	Daily	
811	Fld. 54 (Waipahu)	655	Oahu Sugar Co.	1920	8 a.m.	"		Fld. 49
812	Robinson Camp 2	610	Hawaiian Pine	1924		"		4310
812A	Fld. 50 (Waipahu)	600	Oahu Sugar Co.	1945				
813	Hoaeae (Upper)	750	Hawaiian Pine	1908		Daily	Daily	Robinson Camp 1; 4304
813A	Fld. 60 (Waipahu)	620	Oahu Sugar Co.	1945				

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
814	P.R.I. Wahiawa	880	Pineapple Research Inst.	1937		Daily		
815	Fld. 53 (Waipahu)	650	Oahu Sugar Co.	1923	8 a.m.	"		
816	Fld. 47 (Waipahu)	400	Oahu Sugar Co.	1929	8 a.m.	"		
817	Kipapa Camp 1	680	Hawaiian Pine	1925		"		Fld. 4206
818	Fld. 46 (Waipahu)	500	Oahu Sugar Co.	1939				
819	Fld. 51 (Waipahu)	580	Oahu Sugar Co.					
820	Gage 1 (Libby)	650	Libby, McNeill & Libby	1939	6-8 a.m.	After rain		Waipio A; Fld. 140
821	Pine Spur Camp	810	Hawaiian Pine	1933		Daily		
822	Gage 5 (Libby)	350	Libby, McNeill & Libby	1939	6-8 a.m.	After rain		
823	Kipapa Camp 5	840	Hawaiian Pine	1925		Daily		Fld. 4218
824	Fld. 13 (Waipahu)	370	Oahu Sugar Co.	1935	8 a.m.	"		
825	Kipapa	370	Oahu Sugar Co.	1917	8 a.m.	"		Kipapa 375
825A	Fld. 39 (Waipahu)	510	Oahu Sugar Co.	1929				
826	Fld. 42 (Waipahu)	700	Oahu Sugar Co.	1928	8 a.m.	Daily		Waipahu Fld. 42
827	Kipapa Pump 5	1007	Hawaiian Pine	1925		"		Fld. 4223
830	Gage 2 (Libby)	700	Libby, McNeill & Libby	1916	6-8 a.m.	After rain		Waipio B; P.R.I.
830A	Fld. 41 (Waipahu)	560	Oahu Sugar Co.	1929				
831	Fld. 3C (Waipahu)	370	Oahu Sugar Co.	1920	8 a.m.	Daily		
831A	Ku Tree Dam	1100	Army Engineer	1942		"		
832	Waikakalaua	750	Oahu Sugar Co.	1917	8 a.m.	"		
833	Koolau Dam	1150	Util. Off. U.S.E.D. Schofld.	1914		"	Daily	
834	Gage 7 (Libby)	700	Libby, McNeill & Libby	1946	6-8 a.m.	After rain		Pearl City
834A	Fld. 3 (Waipahu)	600	Oahu Sugar Co.	1920				
835	Fld. 18 (Aiea)	430	Oahu Sugar Co.	1947	6-8 a.m.	Daily		Corner of Fld. 1
836	Waiawa	800	Oahu Sugar Co.	1917	8 a.m.	Twice weekly	Daily	
837	Waiahole	750	Oahu Sugar Co.	1917	8 a.m.	Daily	Daily	
838	Kaneohe Ranch	90	Kaneohe Ranch Co.	1944		Daily	Daily	
839	Kahaluu	360	U.S.G.S.	1935		Recorder		
840	Kaneohe N.A.S.	200	Naval Air Station	1941		Daily	Daily	
841	Kawaihapai	20	Waialua Agri.	1930	6-8 a.m.	Recorder	Daily	W. A. Co. Sta. 2
842	Makaha	1500	Waianae Co.	1911		Weekly	Monthly	Makaha Mauka or Uka
843	Mokuleia	20	Waialua Agri.	1924	6-8 a.m.	Daily		W. A. Co. Sta. 3

OAHU RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
844	Mt. Kaala	4000	Army, APO 959	1931	8 a.m.	Daily	Monthly	
845	Pump 16 (Waialua Ag.)	30	Waialua Agr.	1947	6-8 a. m.	"		
846	Ranch (Waialua)	200	Waialua Agri.	1926	6-8 a.m.	"		Ranch Sta. 4; Ohara Camp
847	Waialua	30	Waialua Agri.	1901	6-8 a.m.	Recorder	Daily	Off roof; Waialua Off.
850	Kemoo Camp 2	90	Waialua Agri..	1934	6-8 a.m.	Daily		
851	Kemoo Camp 5	270	" "	1933	6-8 a.m.	"		W. A. Co., Sta. 5
852	Helemano Camp 4	180	Waialua Agri.	1934	6-8 a.m.	"		W. A. Co., Sta. 7
853	Kaheeka	670	" "	1931	6-8 a.m.	"		Sta. 7; Helemano 7
854	Helemano 9	310	" "	1933	6-8 a.m.	"		
855	Kemoo Camp 8	700	" "	1924	6-8 a.m.	"	Daily	Kemoo Fld. 8; Sta. 6
856	Helemano Res. 6	470	" "	1933	6-8 a.m.	"		Sta. 8
857	Kemoo	950	Cal. Packing Co.	1934	6-7 a.m.	"		Kemoo Farm
859	Fld. 201 (Cal. Pack.)	1000	Cal. Packing Co.	1933	6-7 a.m.	"		
860	Brodie Camp 4	800	Hawaiian Pine	1924		"		Fld. 4446
861	Opaeula 8	690	Waialua Ag. Co.	1929	6-8 a.m.	Recorder		Sta. 13; Camp 8
862	Kemoo Camp	850	Hawaiian Pine	1924		Daily		Fld. 4508
863	Wahiawa Dam	810	Wahiawa Water Co.	1906		"	Daily	W.W. Co. 1; W of Reservoir Wahiawa Water W.
864	Opaeula Camp	880	Hawaiian Pine	1926		Daily		Fld. 4714
865	Pomoho	920	Cal. Packing Co.	1922	6-7 a.m.	"		Pomoho
866	Brodie Camp 2	1000	Hawaiian Pine	1926		"		Fld. 4401
867	Waialua Camp	1000	Hawaiian Pine	1924		"		Fld. 4708
870	Opaeula	1100	Waialua Ag. Co.	1902	6-8 a.m.	"	Daily	Opaeula 1 Reservoir W. A. Co., Sta. 12
871	Helemano Reserv.	1030	Waialua Ag. Co.	1918	6-8 a.m.	Daily	Daily	W.A. Co., Sta. 9; Tanada
872	Wahiawa	920	Cal. Packing Co.	1930	7-8 a.m.	"	"	Wahiawa Lab., Wahiawa (Cal. Pack.)
873	Kaukonahua Camp	1000	Hawaiian Pine	1924		Daily		Fld. 4553
874	Wahiawa Lab.	920	" "	1943		"		
874A	Wahiawa HSPA	1120	HSPA Nursery	1926	8 a.m.	After rain		
875	Helemano Camp	1140	Hawaiian Pine	1926		Daily		

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
876	Waialua (Mauka)	1250	Hawaiian Pine	1926		Daily		Fld. 4716
877	Kamananui Intake	1000	Waialua Ag. Co.	1932	6-8 a.m.	Recorder		
877A	Naval Radio	1200	U.S. Navy, Wah. Nav. Ra.	1905		Daily		
878	Wahiawa Res.	800	Waialua Ag. Co.	1905	5-6 p.m.	"		For. Res. 12; WA Co. 12
879	Poamoho	1400	H.S.P.A. McEldowney			Monthly		
880	Kawai—Iki	1050	Waialua Ag. Co.	1903		Weekly	Monthly	W.A. Co. Sta. 11
880A	South Fork Kaukonahua	1180	Post Engr., Schofield	1942		Monthly		
881	Helemano Intake	1070	Waialua Ag.	1918	6-8 a.m.	Daily	Daily	W.A. Co. Sta. 8
881A	N. Fork Kaukonahua (1250)	1250	USGS	1941		Random		
882	Wahiawa W.C.I.	1200	Wahiawa Water Co.	1907		Weekly	Monthly	Wahiawa Intake
882A	N. Fork Kaukonahua (1150)	1150	USGS	1931		Random		
883	Kahana	800	Oahu Sugar Co.	1917	8 a.m.	Daily	Daily	Kahana 18
883A	Marsh	2700	HSPA			Seldom		
884	Punaluu	40	Kahuku Plant. Co.	1941	6-8 a.m.	Daily	Daily	
885	Waikane	800	Oahu Sugar Co.	1917	8 a.m.	"	Daily	
885A	Kaaawa Mauka	100	F. S. Morgan, Kualoa Ra.	1948		Weekly		
886	Kahana 27	800	Oahu Sugar Co.	1924	8 a.m.	Daily		
886A	Hakipuu	100	F. S. Morgan, Kualoa Ra.	1948		"		
886B	Kaaawa	20	F. S. Morgan, Kualoa Ra.	1948		"		
886C	Kualoa	10	F. S. Morgan, Kualoa Ra.	1948	6-8 a.m.	"		
887	Opaeula Camp 2	110	Waialua Ag. Co.	1933	6-8 a.m.	Daily		Moved often
888	Opaeula 3	70	" " "	1946	6-8 a.m.	After rain		
890	Kawailoa	180	" " "	1916	6-8 a.m.	Daily	Daily	Kawailoa Camp 3; Sta. 16 Kawailoa 3
891	Waimea 8	230	Waialua Ag. Co.	1933	6-8 a.m.	Daily		Kawailoa Camp 8
892	Waimea	360	" " "	1916	6-8 a.m.	Recorder	Daily	Kawailoa A; Sta. 18, Waimea 9; moved 1947 & thereafter called Waimea 3
893	Kawailoa Fld. 15	500	Waialua Ag. Co.	1935	6-8 a.m.	Daily		
894	Kawailoa 19	710	" " "	1929	6-8 a.m.	"		Here since 1942; Sta. 15 Kawailoa 18 Reserv; Fld. 19

OAHU RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
895	Waimea Camp	510	Hawaiian Pine	1924		Daily		Fld. 4803
896	Pupukea Farm	670	Crossley Assoc.	1948		Monthly		
897	Waimea (Mauka)	1000	Hawaiian Pine	1926		Daily		
898	Pupukea 1	1090	HSPA	1928		Monthly		
899	Pupukea 2	1500	"	1928		"		
899A	Dry Land Malaekahana	290	Kahuku Plant.	1947		"		
899B	Pineapple Field	370	Kahuku Plant.	1947		"		
900	Malaekahana Camp	200	Cal. Packing Co.	1917	6-7 a.m.	Daily		
901	Malaekahana	30	Kahuku Plant. Co.	1941	6-8 a.m.	"		Pump 3
902	Fld. 28 (Kahuku)	150	Kahuku Plant. Co.	1946	6-8 a.m.	"		
903	Laie	10	" " "	1941	6-8 a.m.	"	Daily	Stable
904	Hauula	80	" " "	1941	6-8 a.m.	"		
905	Papakoko	40	" " "	1946	6-8 a.m.	"		
906	Kawela 1	280	Cal. Packing Co.	1922		Monthly		Kawela Camp 1
906A	Camp 22 (Cal. Pack.)	400	Cal. Packing Co.	1920		Monthly		
907	Kahuku Pump 2	40	Kahuku Plant. Co.	1941	6-8 a.m.	Daily	Daily	
907A	Camp Kahuku	570	" " "	1947		Weekly		
908	Pump A (Kahuku)	50	" " "	1948	6-8 a.m.	Daily		
910	Pump 10 (Kahuku)	210	" " "	1946	6-8 a.m.	"		
911	Pump 5 (Kahuku)	90	" " "	1946	6-8 a.m.	"	Daily	
912	Kahuku	20	" " "	1920	6-8 a.m.	"	"	

OAHU RAIN GAGES

(Arranged alphabetically)

No.	Name of Station
764	Aiea
766	Aiea 500 (Fld 65)
746	Apokaa
701	Barbers Point
712A	Beaumont
717	Black Point
705	Board of Water Sup. Office
866	Brodie Camp 2
860	Brodie Camp 4
907A	Camp Kahuku
906A	Camp 22 (Cal. Pack.)
710A	Clement
720A	Collins
705A	Craigside
720	D.P.D.
899A	Dry Land Malaekahana
741	Ewa
754	Field 2 (Aiea)
834A	Field 3 (Waipahu)
831	Field 3C (Waipahu)
752C	Field 4 (Waipahu)
752B	Field 5 (Waipahu)
748	Field 12 (Waipahu)
824	Field 13 (Waipahu)
745A	Field 15 (Waipahu)
835	Field 18 (Aiea)
742A	Field 19 (Waipahu)
740A	Field 24 (Waipahu)
740B	Field 26 (Waipahu)
739	Field 27A (Waipahu)
902	Field 28 (Kahuku)
733	Field 29 (Waipahu)
808	Field 32 (Cal Pack)
809	Field 33 (Cal Pack)
762	Field 34 (Aiea)
752A	Field 34 B (Waipahu)
738B	Field 38 B (Waipahu)
825A	Field 39 (Waipahu)
760	Field 41 (Aiea)
830A	Field 41 (Waipahu)
826	Field 42 (Waipahu)
763	Field 44 (Aiea)
735	Field 46 (Ewa)
818	Field 46 (Waipahu)
816	Field 47 (Waipahu)
764A	Field 49 (Aiea)
812A	Field 50 (Waipahu)
819	Field 51 (Waipahu)
815	Field 53 (Waipahu)
811	Field 54 (Waipahu)
809A	Field 56 (Waipahu)
738A	Field 57 (Waipahu)
738	Field 59 (Waipahu)
813A	Field 60 (Waipahu)
747	Field 62 (Ewa)
767	Field 66 (Aiea)
765	Field 71 (Aiea)
744	Field 75 (Ewa)
751	Field 79.1 (Ewa)
807	Field 84 (Cal Pack)
729	Field 85-86 (Cal Pack)
729A	Field 86 (Cal Pack)
731	Field 151 (Cal Pack)
859	Field 201 (Cal Pack)
758	Fleet Weather Central
820	Gage 1 (Libby)
830	Gage 2 (Libby)
734	Gage 3 (Libby)
822	Gage 5 (Libby)
834	Gage 7 (Libby)
886A	Hakipuu
771	Halawa North Uka
904	Hauula
875	Helemano Camp
852	Helemano Camp 4
881	Helemano Intake
871	Helemano Reserv.
856	Helemano Reserv. 6
854	Helemano 9
757	Hickam Field
813	Hoaeae Upper
703	Honolulu WBAS
704	Honolulu (WBO)
707	HSPA Exp. Station
886B	Kaaawa
885A	Kaaawa mauka
722	Kahala
839	Kahaluu
883	Kahana
886	Kahana 27
853	Kaheeka
912	Kahuku
907	Kahuku Pump 2
715	Kaimuki
777	Kalihi Reserv. Site
776	Kalihi Tunnel 2
774	Kalihi U.S.G.S.
797	Kamaile Pump
877	Kamananui Intake
781	Kaneohe (Mauka)
840	Kaneohe N.A.S.
838	Kaneohe Ranch
773	Kapalama
873	Kaukonahua Camp
841	Kawaihapai
880	Kawai-iki
890	Kawailoa
893	Kawailoa Field 15
894	Kawailoa 19
790	Kawailoa Girls School
906	Kawela 1
857	Kemoo
862	Kemoo Camp
850	Kemoo Camp 2
851	Kemoo Camp 5
855	Kemoo Camp 8
825	Kipapa
817	Kipapa Camp 1
823	Kipapa Camp 5
827	Kipapa Pump 5
804A	Kolekole Pass
789	Konahuanui
833	Koolau Dam
886C	Kualoa
806	Kunia Camp
831A	Kutree Dam
903	Laie
805	Leilehua
782	Luakaha (lower)
804	Lualualei
842	Makaha
800	Makahana Ditch
796	Makaha Kai
724	Makapuu Point
901	Malaekahana
900	Malaekahana Camp
712	Manoa
785	Manoa H.S.P.A.
716	Manoa Tunnel 2
883A	Marsh
720	Matsonia Drive
787	Maunawili Ranch
702A	MCAS Ewa
725	Mikilua
770	Moanalua
772	Moanalua U.S.G.S.
843	Mokuleia
844	Mt. Kaala
877A	Naval Radio
882A	N. Fork Kaukonahua (1150)
881A	N. Fork Kaukonahua (1250)
710	Nutridge
783	Nuuanu Dam 4
774A	Nuuanu Orchid Gard.
786	Nuuanu Pali

OAHU RAIN GAGES

(Arranged alphabetically)

No.	Name of Station
775	Nuuanu Reserv. 5
870	Opaeula
864	Opaeula Camp
887	Opaeula Camp 2
888	Opaeula 3
861	Opaeula 8
706	Pacific Heights
718	Palolo Valley
905	Papakoko
784	Pauoa Flats
755	Pearl Harbor
899B	Pineapple Field
821	Pine Spur Camp
879	Poamoho
865	Pomoho
802	Power House
711	P.R.I. (Dole St.)
814	P.R.I. Wahiawa
743	Pump 2 (Ewa)
908	Pump 4 (Kahuku)
745	Pump 4 (Waipahu)
911	Pump 5 (Kahuku)
753	Pump 6 (Waipahu)
742	Pump 7 (Ewa)
727	Pump 10 (Ewa)
910	Pump 10 (Kahuku)
845	Pump 16 (Waialua Ag.)
884	Punaluu
706A	Punchbowl
728	Puu Manawahua
898	Pupukea 1
899	Pupukea 2
896	Pupukea Farm
846	Ranch (Waialua)
768	Red Hill
740	Reserv. 5 (Ewa)
732	Reserv. 6 (Ewa)
730	Reserv. 6B (Ewa)
736	Reserv. 8 (Ewa)
737	Reserv. 9 (Ewa)
812	Robinson Camp 2
714A	Spiegelberg
788	St. Stephens Semin.
708	Tantalus (1050)
714	Tantalus (1400)
780	Tantalus Peak
722A	Thorne
702	U.S. Magn. Observ.
713	University Farm
872	Wahiawa
863	Wahiawa Dam
874A	Wahiawa HSPA
874	Wahiawa Lab.
878	Wahiawa Res.
882	Wahiawa (WCI)
837	Waiahole
847	Waialua
867	Waialua Camp
876	Waialua (Mauka)
798	Waianae
803	Waianae (Mauka)
801	Waianae Valley
836	Waiawa
832	Waikakalaua
885	Waikane
723	Wailupe
756	Waimalu
761	Waimalu (500)
794	Waimanalo
700	Waimanalo Stable
892	Waimea
891	Waimea 8
895	Waimea Camp
897	Waimea (Mauka)
750	Waipahu (Office)
752	Waipio
810	Wheeler Field
721	Wilhelmina Rise
716A	Woodlawn

40'

159° 30'

20'

10'

10'

22° 00'

22°

KILAUEA SUGAR

HAW'N CAN.

H.C.Co

LIHUE PL'N.

HAW'N FRUIT PACKERS

LIHUE PL'N

KAPAA

LIHUE PL'N

LIHUE

GROVE FARM

GROVE FARM

KEKAHA SUGAR CO.

WAIMEA SUGAR

GAY & ROBINSON

OLOKELE SUGAR CO. LTD.

McBRYDE SUGAR CO. LTD.

KAUAI PINEAPPLE

KAUAI PINE

KOLOA SUGAR CO.

EXPLANATION OF SYMBOLS

- ○ A single circle is a gage read daily or after each rain
- ◎ A double circle is a recording rain gage
- △ A triangle is a gage read weekly, monthly, or intermittently
- ---- The longer dashes are field boundaries or property lines
- ..... The series of dots are the primary roads

MILES

0 1 2 3 4 5

KAUAI RAIN GAGES OPERATING MAY 1, 1948

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
925	Field 3 (Olokele)	110	Olokele Sugar Co.	1947	0800	Daily		
926	Burns Field	20	C.A.A.			"		C.A.A.-1
927	Eleele	163	McBryde Sugar Co.	1904	0630	Daily except week ends	Daily	
928	Kalaheo Field K-1	750	Kauai Pine. Co.	1943	0700	Daily and Recorder		Kalaheo; Fld. K-1 Standard & Recording gages
930	Wahiawa	213	McBryde Sugar Co.	1908	0700	Daily except week ends	Daily	
931	West Lawai	210	" " "	1905	0600	Daily except week ends	Daily	
933	Paanau	450	Kauai Pine. Co.	1938	0730	Daily		Field 34
934	East Lawai	441	McBryde Sugar Co.	1905	0630	Daily except week ends	Daily	
935	Kukuiula	78	" " "	1906	0530	Daily except week ends	Daily	Koloa
936	Koloa	241	Koloa Sugar Co.	1887	0730	Daily	Daily	Office
937	Koloa Mill	155	" " "	1924	0630	"	"	
940	Puuhi	80	" " "	1907	0700	"	"	
941	Mahaulepu	86	" " "	1907	0800	"	"	
942	Kaunalewa	9	Kekaha Sugar Co.	1946	0800	After rain		
943	Waiawa	38	" " "	1935	0800	" "	Daily	
944	Kekaha	9	" " "	1933	0800	" "	"	
945	Hukipo	800	" " "	1940	0800	" "	"	
947	Waimea	10	Waimea Sugar Co.	1911	0800	Daily	"	
950	Waikaia	250	Gay & Robinson	1942	var.	After rain		
951	Pakala	30	" " "	1942	var.	" "		
952	Nonopahu Res.	800	" " "	1942	var.	" "		
953	Kaawanui	400	" " "	1942	var.	" "		
954	Nonopahu #6	1030	" " "	1942	var.	" "		
955	Aaka	900	" " "	1942	var.	" "		
962	Field 13 (Olokele)	135	Olokele Sugar Co.	1941	0800	Daily		
965	Makaweli	140	" " "	1895	0800	"	Daily	Office

KAUAI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
966	Field 36 (Olokele)	471	Olokele Sugar Co.	1941	0800	Daily		
981	Field 37 (Olokele)	350	" " "	1941	0800	"		
983	Alexander Res.	1609	McBryde Sugar Co.	1926	0700	Daily except week ends		
985	Homesteads	712	" " "	1913	0700	Daily except week ends	Daily	Kalaheo; Homestead
986	Kalaheo Fld. Office	800	Kauai Pine. Co.	1925	0630	Daily		Kalaheo; Field Office
990	Wahiawa Mountain	2100	McBryde Sugar Co.	1904		Monthly	Monthly	Marsh
992	Omao	525	Kauai Pine. Co.	1941	0730	Daily		Field M
993	Puuohewa	500	Koloa Sugar Co.	1924	0730	"		
994	Koloa Mauka	640	" " "	1904	0800	"	Monthly	Mauka
995	Koloa Field 52	600	" " "	1946	0630	"	Daily	Field 52; Koloa Field
996	Kamooloa	721	McBryde Sugar Co.	1926	0630	"	"	
997	Papuaa	538	Grove Farm Co.	1915	0600	"	"	Papuaa Res.
1000	Koloa Gap	600	Kauai Pine. Co.	1947	0730	"		Field 22-D
1001	M & M	300	Koloa Sugar Co.	1924	0730	"		
1002	Wai Tah	248	" " "	1946	"	"		
1003	Kaala	400	" " "	1924	"	"		
1004	Reservoir #6	420	Grove Farm Co.	1912	0800	"	Monthly	Field #31
1005	Kaluahonu	330	Koloa Sugar Co.	1924	0730	"	Daily	
1006	Halenanaho	490	Grove Farm Co.	1932	0800	"	Monthly	Fld. #25; Halenanaho Res.
1007	Aakukui	330	" " "	1909	0630	"	Daily	Aakukui Camp
1011	Reservoir #5	385	" " "	1935	0730	"	Daily	Fld. #22-A
1012	Gage 18-A (Grove F.)	260	" " "	1945	"	"		
1013	Puhi	329	" " "	1935	"	"	Daily	New Office
1015	Molokoa	200	Mrs. Isenberg	1892	0800	"	"	
1016	Gage 4-A (Grove F.)	275	Grove Farm Co.	1940	0700	"		
1017	Malumalu	250	" " "	"	0730	"	Daily	11-C; Fld. 11
1020	Lihue	207	Lihue Planta. Co.	1915	1600	"	"	
1021	Grove Farm	200	Grove Farm Co.	1885	0730	"	"	Old G. F. Office
1022	Hanamaulu	175	Lihue Planta. Co.	1915	0530	"	"	
1023	Barking Sands	10	C.A.A.		Unknown	"		

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
1024	Fld. 242 (Kekaha)	10	Kekaha Sugar Co.	1946	0830	After rain		
1025	Fld. 246-2 (Kekaha)	10	" " "	1946	0830	" "		
1026	Mana	11	" " "	1945	0900	" "	Daily	Mana Office
1027	Limaloa	10	" " "	1946	0800	" "		
1030	Field H (Kekaha)	45	" " "	"	0830	" "		
1031	Saki Mana	10	" " "	1945	"	" "		
1032	Field A (Kekaha)	35	" " "	1946	"	" "		
1033	Kolo	36	" " "	1936	0900	" "	Daily	Field U
1034	Camp 3	12	" " "	1946	0800	" "		
1035	Niu Ridge	1250	" " "	1939	"	" "	Daily	Puu Opae
1037	Puu Opae Garden	2250	" " "	1946	0900	" "		
1040	Puehu Ridge	1750	" " "	1936	0700	" "	Daily	Fld. G-1; Pokii Ridge
1042	Waialea	3600	U.S.G.S.	1926		Irregular		
1044	Keanakua	4450	"	1921		Annually	Annually	
1047	Mt. Waialeale	5075	"	1912		Annually	Annually	
1050	Iliiliula Intake	1070	Lihue Planta. Co.	1935		Monthly	Monthly	
1051	N. Wailua Ditch	1200	U.S.G.S.	1928		"	Monthly	
1052	Waiahi (Upper)	780	Lihue Planta. Co.	1927	Afternoon	Daily	Daily	New Power House
1053	Hanalei Tunnel	1218	U.S.G.S.	1928		Monthly	Monthly	
1054	Waiahi (Lower)	550	Lihue Planta. Co.	1936	Afternoon	Daily	Daily	
1055	N. Wailua River	650	U.S.G.S.	1929		Monthly	Monthly	
1057	Kanaha Ditch	550	Lihue Planta. Co.			Daily	Monthly	
1061	EKW #5	452	" " "	1933	0530	Daily		
1062	Wailua Uka	250	" " "	1925	"	"		
1063	Wailua (H.F.P.)	350	Hawaiian Fruit Packer	1948	0730	"		Crossley's
1064	Camp 9	275	" " "	"	0530	"		
1065	Wailua Kai	70	" " "	"	0530	"		
1066	Wailua Kai #2	11	" " "	1934	0530	"		
1067	Lot 143 (Lihue)	340	" " "	1941	0530	"		
1070	Field P (Kekaha)	10	Kekaha Sugar Co.	1946	0830	After rain		
1071	Makaha	1700	Duvel	1947		Monthly		
1072	Puuhinahina	3435	"	1945		Weekly		Kaana

KAUAI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
1075	Kanalohuluhulu	3600	Duvel	1945		Weekly		Kokee Ranger Station
1077	Kalalau	850	U.S.G.S.	1937		Irregular	Annually	
1080	Paukahana	3723	"	1922		"	"	
1082	Waiakoali Camp	3450	"	1922		"	"	
1083	Mohihi	3500	"	1921		"	"	Mohihi Upr. Cr.
1084	Kilohana	4023	"	1926		"	"	Alakai
1085	Mohihi-Koaie Divide	3920	"	1926		"		
1086	Intake, Wainiha P.C.	700	McBryde Sugar Co.	1910	1200	Daily	Daily	Wainiha Intake; W. Power Canal Intake
1092	Kaneha	843	Lihue Plantation Co.	1916	0530	Daily		
1094	EKW #3	409	" " "	1933	"	"		Matsumura
1095	Mimino	279	" " "	1934	"	"		
1097	EKW #4	333	" " "	1933	"	"		
1100	Kapahi	150	Haw'n Fruit Pack.	1947	0700	Daily except week ends		
1101	Field Lihue #2	300	Haw'n Canneries	1938	0730	Daily		
1102	Old Camp	350	Lihue Plantation Co.	1921	0530	Daily		
1104	Kapaa Stables	68	" " "	1917	"	"	Daily	
1107	EKW #1	122	" " "	1933	"	"		
1110	Halaula	253	" " "	1916	"	"	Daily	
1111	Anahola	40	Haw'n Canneries	1931	0730	"	"	
1112	Kealia	11	Lihue Plantation Co.	1916	0530	"	"	
1113	Station 9 (Lihue)	150	" " "	1941	"	"		
1114	Anahola-Lihue	186	" " "	1934	"	"		
1115	Powerhouse Wainiha	101	McBryde Sugar Co.	1910	1800	"	Daily	
1117	Princeville Plantation	295	Princeville Plantation Co.	1910	Unknown	"	"	
1131	Kalihiwai Reservoir	400	Kilauea Sugar Plant. Co.	1936	0730	After rain	"	
1132	Field 12 (Kilauea)	290	" " " "	"	"	" "		
1134	Kilauea	317	" " " "	1885	1530	" "	Daily	Office
1135	Puu Ka Ele Res.	415	" " " "	1936	0730	" "	"	Puu Ka Ele; Puukaele Res.
1136	Morita	340	" " " "	"	"	" "		
1137	Koloko Reservoir	737	" " " "	"	"	" "	Daily	Koloko

KAUAI RAIN GAGES OPERATING MAY 1, 1948—Continued

Gage No.	Name	Elev. In Feet	Maintained By	Year Began	Time Of Reading	Frequency Of Reading	Published By U. S. Weather Bureau	Other Names And Remarks
1140	Waikalua	300	Kilauea Sugar Plant. Co.	1936	0730	After rain		
1141	Pilaa	280	" " " "	"	"	" "		Koolau
1142	Moloaa Camp #1	300	Haw'n Canneries	1938	0730	Daily		
1143	Lepeuli	360	Kilauea Sugar Plant. Co.	1936	"	After rain		
1144	Moloaa Field 7-A	250	Haw'n Canneries	1936	"	Daily		
1145	Moloaa	330	" "	1926	"	"	Daily	Moloaa Fld. 5 Puu Au Au

KAUAI RAIN GAGES

(Arranged alphabetically)

No.	Name of Station
955	Aaka
1007	Aakukui
983	Alexander Res.
1111	Anahola
1114	Anahola-Lihue
1023	Barking Sands
926	Burns Fld.
1034	Camp 3 (Kekaha)
1064	Camp 9 (Lihue)
934	East Lawai
1107	EKW #1
1094	EKW #3
1097	EKW #4
1061	EKW #5
927	Eleele
1032	Field A (Kekaha)
1030	Field H (Kekaha)
1101	Field Lihue 2 (Hawn. Can.)
1070	Field P (Kekaha)
925	Field 3 (Olokele)
1132	Field 12 (Kilauea)
962	Field 13 (Olokele)
966	Field 36 (Olokele)
981	Field 37 (Olokele)
1024	Field 242 (Kekaha)
1025	Field 246-2 (Kekaha)
1016	Gage 4A (Grove Farm)
1012	Gage 18A (Grove Farm)
1021	Grove Farm
1110	Halaula
1006	Halenanaho
1053	Hanalei Tunnel
1022	Hanamaulu
985	Homesteads
945	Hukipo
1050	Iliiliula Intake
1086	Intake, Wainiha P.C.
1003	Kaala
953	Kaawanui
928	Kalaheo Fld. K-1
986	Kalaheo Fld. Office
1077	Kalalau
1131	Kalihiwai Res.
1005	Kaluahonu
996	Kamooloa
1057	Kanaha Ditch
1075	Kanalohuhulu
1092	Kaneha
1104	Kapaa Stables
1100	Kapahi
942	Kaunalewa
1112	Kealia
1044	Keanakua
944	Kekaha
1134	Kilauea
1084	Kilohana
1033	Kolo
936	Koloa
995	Koloa Field 52
994	Koloa Mauka
937	Koloa Mill
1000	Koloa Gap
1137	Koloko Res.
935	Kukuiula
1143	Lepeuli
1020	Lihue
1027	Limaloa
1067	Lot 143 (Lihue)
1001	M & M
941	Mahaulepu
1017	Malumalu
1071	Makaha
965	Makaweli
1026	Mana
1095	Mimino
1083	Mohihi
1085	Mohihi-Koaie Divide
1142	Moloaa Camp 1
1145	Moloaa
1144	Moloaa Fld. 7A
1015	Molokoa
1136	Morita
1047	Mt. Waialeale
1035	Niu Ridge
952	Nonopahu Res.
954	Nonopahu #6
1051	N. Wailua Ditch
1055	N. Wailua River
1102	Old Camp
992	Omao
933	Paanau
951	Pakala
997	Papuaa
1080	Paukahana
1141	Pilaa
1115	Power Hse., Wainiha
1117	Princeville Plantation
1040	Puehu Ridge
1013	Puhi
1135	Puu Ka Ele Res.
1037	Puu Opae Garden
940	Puuhi
1072	Puuhinahina
993	Puuohewa
1011	Reservoir #5 (Grove Farm)
1004	Reservoir #6 (Grove Farm)
1031	Saki Mana
1113	Station 9 (Lihue)
930	Wahiawa
990	Wahiawa Mtn.
1002	Wai Tah
1054	Waiahi (Lower)
1052	Waiahi (Upper)
1082	Waiakoali Camp
1042	Waialea
943	Waiawa
950	Waikaia
1140	Waikalua
1063	Wailua (H.F.P.)
1065	Wailua Kai
1066	Wailua Kai #2
1062	Wailua Uka
947	Waimea
931	West Lawai

A History of the Pathology Department, Experiment Station, H.S.P.A. 1905-1945

By J. P. MARTIN

CONTENTS

Introduction

The Honorable W. L. Lee in his presidential address before the Royal Hawaiian Agricultural Society in 1854 stated in part, "In January a storm came, accompanied with terrible thunder and lightning, and blasted our smiling fields (The Lihue Plantation Company) as with the breath of fire. After the storm passed, the cane fields grew brown, rotted and died, and 400 acres that should have brought us at least $50,000.00, hardly produced one-sixth part of that sum."

"The whole crop did not exceed fifty tons. The cause of this fire blight is still a mystery. At first we thought that it might be the work of an insect, but the closest examination showed that we were mistaken, and we can ascribe it to nothing but some great convulsion in the atmosphere."

This is one of the first (if not the first) accounts of a disease attacking sugar cane in Hawaii. On the basis of present knowledge, the aforementioned losses very probably resulted from eye spot disease. Growth failure of Lahaina cane was reported in localized areas on Hawaii as early as 1883 and by 1905 this condition, later known as root rot, occurred on the other Islands and had caused marked reductions in sugar yields in a number of instances. Prior to 1905, certain other cane diseases were causing considerable concern on various plantations, particularly leaf disorders, and the rotting of stalks and newly planted cuttings. Serious economic losses from disease in other sugar-producing countries had taken place. For example, root rot of Lahaina cane caused this variety to fail in one country after another, and sereh disease almost caused a collapse of the Java sugar industry in 1883 and 1884.

The Hawaiian sugar planters were cognizant of crop losses resulting from diseases in the local and foreign sugar industries, and in other agricultural crops throughout the world. They also recognized the fact that large economic losses might occur if no measures of disease control were at their disposal. In order to deal with the current infectious maladies and to be prepared to satisfactorily combat new diseases, the Trustees of the Hawaiian Sugar Planters' Association decided in 1904 to organize a new division at the Experiment Station, to be known as the Division of Pathology and Physiology. The function of this division would be to study the local cane diseases and to offer ways and means for controlling them under field conditions. During the latter part of 1904, the Experiment Station Committee, with W. M. Giffard as Chairman, began to search for a pathologist to take charge of the newly organized division.

Personnel and Facilities

Staff:

Dr. N. A. Cobb (Pathologist, Department of Agriculture, N. S. W., Australia) was selected for this new position and joined the Station Staff in March 1905 as Director of the Division of Pathology and Physiology, at which time the first active work in plant pathology was initiated. During 1905 Cobb organized the division, planned a building, equipped the laboratories, and acquired a plot of land suitable for conducting experimental work on sugar-cane diseases. The major sugar-cane diseases and problems investigated by Cobb were root diseases, leaf diseases (eye spot, ring spot), Pahala blight (leaf-splitting disease), rind disease, iliau, lightning injury (top rot), nematode damage, the disinfection of cane cut-

tings, and the anatomy of the cane plant. It is evident from the foregoing list that a number of cane diseases were already problems of serious importance in the sugar industry. Cobb resigned in April 1907 to accept the position as Chief of the Division of Crop Technology, U. S. D. A.

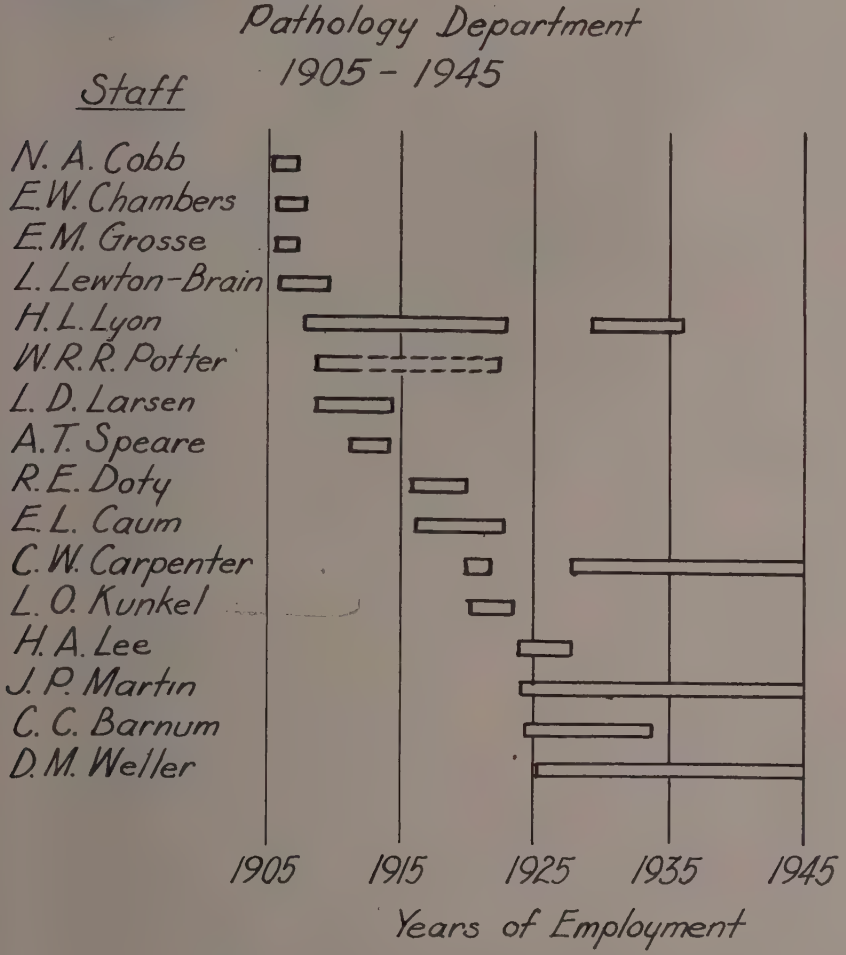

Fig. 1. Staff members—Pathology Department.

During the past forty years (1905-1945), the research work in plant pathology and related subjects has been carried on by sixteen staff members (Fig. 1). Before discussing the position that cane diseases have played in the industry and how they have been controlled, the other fifteen members will be introduced chronologically.

E. W. Chambers (Artist and Engraver of the Department of Agriculture, N. S. W.) was employed in June 1905, as illustrator (in part) to the division. A number of Chambers' illustrations, drawings, and paintings are still being used today. Chambers resigned in 1908 to join the U. S. D. A. where he continued to apply his artistic ability.

E. M. Grosse (Artist and Assistant in Pathology, Department of Agriculture, N. S. W.) was engaged in July 1905 and began his work as an assistant in the division. Grosse did some illustration work but his time was devoted chiefly to routine work of the division. Grosse resigned along with Cobb in April 1907.

L. Lewton-Brain (Mycologist and Lecturer, Imperial Department of Agriculture, West Indies) joined the division as Assistant Director in August 1905 and became Director of the division in April 1907, following Cobb's resignation. Lewton-Brain specialized on red rot, root diseases, eye spot, rind disease and the bacterial flora of Hawaiian sugars. He resigned from the Station in August 1909 and later became Director of Agriculture, Federated Malay States.

Dr. H. L. Lyon (Assistant Professor in Botany, University of Minnesota) joined the division in September 1907 as Assistant Pathologist. When the Experiment Station was reorganized (1909) under one Director, the Division of Pathology and Physiology was changed to the Department of Pathology, with Lyon as Pathologist. The Pathology Department was combined with the Department of Botany and Forestry in 1918, with Lyon in charge. All pathological work during the 1909-1923 period was under the direction of Lyon. Lyon became Consulting Pathologist in 1929 and Director of the Experiment Station in 1936. The diseases and projects pertaining to pathology that received his special attention are: iliau, mosaic, eye spot, root rot, growth failure, Pahala blight, top rot, red rot, Fiji disease, sereh, malgrowths, pineapple and forest diseases, collection of fungi, sugar-cane anatomy, and sugar-cane quarantine.

W. R. R. Potter was engaged as artist in July 1908 to carry on the work of Chambers. A number of paintings and drawings of cane diseases by Potter have been reproduced for publication. Shortly after Potter joined the division, he took over all the illustration work of the Experiment Station and continued in this capacity until he resigned in April 1922.

L. D. Larsen (Massachusetts Agricultural College) was employed in September 1908 as Assistant Pathologist in the division. Larsen worked chiefly on eye spot, ring spot, rind disease, red rot and various minor leaf maladies of sugar cane. He also investigated the diseases of the pineapple and published his findings in 1912. Larsen was assigned to the Agriculture Department in March 1914 for special work and did not return to the Pathology Department.

A. T. Speare (Harvard University) was added to the department in February 1911 as Assistant Pathologist. His work dealt chiefly with fungi parasitic on insects. He also investigated red rot, pineapple disease and rind disease. During 1914 Speare was called upon to assist in the work of the Agriculture Department and resigned from the Station October 1915.

R. E. Doty (University of California) joined the department in December 1915 as Assistant in Pineapple Investigations. He carried out chiefly the field work in connection with pineapple diseases. Doty joined the Army in August 1917 and returned to the department as Assistant in Cane Diseases in September 1919. He took an active part in determining field losses from mosaic disease by installing and harvesting field experiments and conducting field surveys. Doty left the department in 1920 when he was assigned to work on the 1920 strike losses.

E. L. Caum (Swarthmore College, Pa.) was employed in February 1916 as Assistant Pathologist. Caum prepared and published a check list of sugar-cane fungi, which has been used extensively as a reference here and in other sugar-cane

producing countries. He studied various leaf diseases of sugar cane and devoted considerable time to seedling and bud selection work. Caum resigned from the Station in October 1922 but returned to the Botany and Forestry Department in 1926.

C. W. Carpenter (Pathologist, Hawaii Agricultural Experiment Station, U. S. D. A.) joined the department in November 1919 as Associate Pathologist. Carpenter resigned in October 1921. He returned to the Pathology Department in July 1927 as Assistant Pathologist and became Associate Pathologist in January 1929. The major projects investigated by Carpenter were root rot and growth failure, brown stripe, chlorotic streak, leaf scald, pokkah boeng, stem galls, mosaic, diseases of agricultural crops, deterioration of cane juices by microorganisms, yeasts and yeast production from molasses, and penicillin.

Dr. L. O. Kunkel (Pathologist, Bureau of Plant Industry, U. S. D. A.) was employed in February 1920 as Associate Pathologist. Kunkel worked almost entirely on sugar-cane and corn mosaic diseases. Cytological studies of Fiji disease were also carried out. Kunkel resigned in June 1923 to accept a position with the Boyce-Thompson Institute, where he continued his studies on plant virus diseases.

H. Atherton Lee (Mycologist, Bureau of Science, Philippine Islands) joined the department in December 1923 as Pathologist, at which time the Pathology Department was separated from the Department of Botany and Forestry. Lee devoted special attention to red stripe, eye spot, root rot, growth failure, mosaic, pokkah boeng, leaf burn, banded chlorosis, tangle top, stem galls, and the distribution of cane roots in the soil. Lee resigned in September 1927 to accept a position with the Philippine Sugar Association, P. I.

J. P. Martin (Assistant in Pathology Department, University of California) joined the department in January 1924 as Assistant Pathologist and was appointed Pathologist in 1929. The major projects investigated by Martin are red stripe, eye spot, brown stripe, chlorotic streak, leaf scald, mosaic, Fiji disease, stem galls, diseases of agricultural crops, nutritional studies of the cane plant, plant quarantine, soilless agriculture, soil microbiology, penicillin, and sugar-cane anatomy

C. C. Barnum (Research Student, Department of Pathology, University of California) was employed in April 1924 as Assistant Pathologist and was made Associate Pathologist in 1929. The principal problems studied by Barnum were red stripe, eye spot, brown stripe, root rot, growth failure, mosaic, rat control, and potash determinations in soils by the Aspergillus method. Barnum resigned in September 1933.

D. M. Weller (University of Chicago) joined the department in February 1925 as Histologist. Weller has carried out histological studies of a number of diseases, but especially red stripe, leaf scald, eye spot, and chlorotic streak. Other projects having received his attention are chromosome studies, effects of colchicine and growth-promoting substances on the cane plant, the distribution of cane roots in the soil, root pressure liquids, pollen studies, root development from root primordia, sugar-cane anatomy, and penicillin.

The department's two foremost responsibilities in the sugar industry have always been the field control of local cane diseases and the exclusion of foreign cane diseases by quarantine. Each subject, project, or disease will be discussed separately to bring out the activities of the department in these fields.

Fig. 2. Pathology building—1905.

Fig. 3. Main room in Pathology building—1905.

Pathology Building:

The wooden building erected in 1905 (Fig. 2.) for the division was especially designed for microscopic, illustrative and photographic work, and the labora-

tories were well equipped for conducting research work on pathological problems. One large room was devoted to the library, museum and for meetings (Fig. 3). This building has served its purpose remarkably well. An addition was made to the original building in 1929.

Fig. 4. Pathology Plot—1905.

Pathology Plot:

The plot of ground secured in 1905 (Fig. 4) for experimental work with sugarcane diseases is still in use. This area, known as the Pathology Plot (corner of Alexander and Bingham Streets), has afforded excellent opportunities for studying certain diseases which could not be brought on the Station grounds proper. Three quarantine houses were constructed on this area (1923, 1925, and 1926), and many imported cane varieties, which have contributed greatly to local sugar production and cane breeding, were grown in these houses and later in the experimental area, prior to their release.

Molokai Quarantine Station:

Since 1928, all quarantine houses and equipment used for importing foreign cane material, either as cuttings or cane seed, have been located on Molokai, where sugar cane is not commercially grown. Methods for handling imported cane material have been perfected by the quarantine committee of the Experiment Station in order to reduce to a minimum the possibility of introducing a foreign disease or insect. It is interesting to note that no disease or insect foreign to Hawaii has been intercepted on any imported cane material while under quarantine. Maintaining an efficacious quarantine against diseases has been a major project of the department and each staff member has taken an active part in this very important Station project.

Scope of Activities

Sugar-Cane Pathology:

Investigations on specific cane diseases were inaugurated immediately after the division was organized. Some of the first diseases studied were eye spot, root rot, red rot, rind disease, iliau and top rot.

Members of the division began making plantation inspections in 1905 in order to have a first-hand knowledge of the cane disease situation throughout the Territory. This service has been continued and has played a major part in dealing with the local diseases and their control.

From the very beginning, specimen material of diseased cane plants was sent from the plantations to the department for diagnosis. It was necessary in a number of instances to visit a plantation in order to study all environmental factors which may have had a direct bearing on the disease before a final diagnosis was reached. Valuable information on cane diseases has been accumulated since the department was first established as the result of the interest taken by the plantation personnel in forwarding disease specimens to the department.

A number of the specimens received from the plantations and collected by members of the department during their field inspections have been preserved and are now present in the museum. Such material has been extremely useful as a reference in later years, when the same or a similar disease was being investigated.

General Pathology:

Diseases affecting agricultural crops (other than sugar cane), forest trees and ornamental plants have at all times received the attention of the pathologists. In a number of instances certain diseases became very active projects of the department. The plants which have received the greatest amount of study in connection with diseases and their control have been taro, banana, potato, tomato, pineapple, avocado, cactus and corn.

The growing of food crops in gardens on the plantations and substations has always been encouraged and practiced. During World Wars I and II, diversified agriculture under the direction of the H. S. P. A. in relation to emergency food production became of paramount importance. New crops were grown for the first time and these as well as the established crops were subject to attack by many organisms. Year-round climatic conditions in Hawaii are highly conducive to the development of organisms causing plant diseases. These same organisms are held in check under mainland conditions by the unfavorable weather conditions during the winter months. A list of the more important diseases of various plants that have been investigated is maintained as a matter of record. The host plant in each case is given, followed by the name of the disease, its cause and the locality from which it was collected or studied.

In 1907 Lyon began collecting Hawaiian fungi on the different Islands. This collection formed a nucleus for our present herbarium which now contains over 2,000 named specimens of Hawaiian, mainland and foreign fungi. Various members of the department have added specimens to the collection as such material became available. The collection has been extremely valuable for reference studies and identification of plant diseases.

Foreign Diseases and Foreign Travel:

Hawaii occupies an isolated position in relation to other sugar-producing countries of the world. This unique geographic location and the rigid quarantine which prevents the free interchange of sugar-cane varieties with other countries have been responsible for the scarcity in Hawaii of the major sugar-cane diseases of the world. The majority of the major foreign diseases are systemic and are readily transmitted with cane cuttings from one country to another. The spread of certain diseases has been traced in several instances to the unrestricted inter-

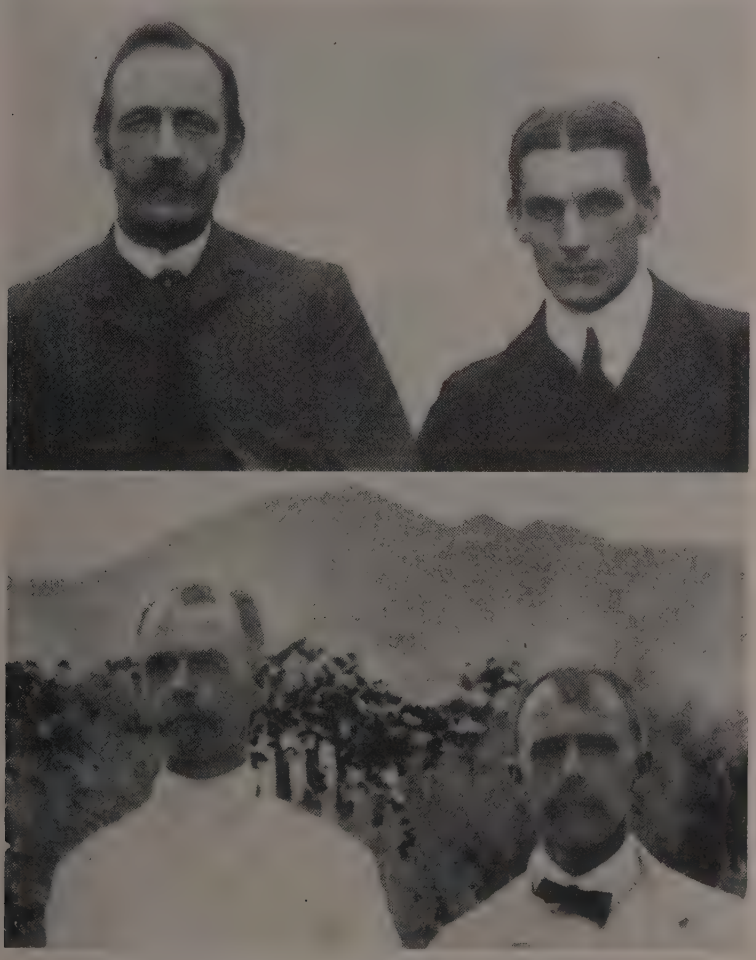

Fig. 5. Top: N. A. Cobb and L. Lewton-Brain.
Bottom: E. M. Grosse and E. W. Chambers.

change of cane cuttings between countries. The importance of a quarantine system for handling imported varieties from foreign countries cannot be too greatly emphasized. The most economical control of a foreign disease is its total exclusion.

Foreign cane diseases are of major significance to the local sugar industry,

first, because it is essential that these diseases do not become established in Hawaii; their potentiality for harm under local conditions cannot be accurately predicted. The Federal and Territorial quarantine laws and the quarantine procedure as executed by this Station regarding the importation of foreign varieties have to date been effective in excluding foreign diseases. Second, it is necessary to have a knowledge of each foreign disease so that it may be intercepted, or, if introduced, eradicated before it becomes widespread. New diseases may gain entrance into a locality when cane cuttings or other plants are imported surreptitiously or openly by persons uninformed with regard to quarantine regulations. Third, a knowledge of the contributing factors which tend to increase the severity of such diseases, and a familiarity with the measures for controlling them, as determined by other investigators, is needful information.

A first-hand knowledge of foreign diseases can best be attained by studying them in the country where they occur. Pathologists from this Station have visited almost all of the sugar-producing countries and have studied and discussed the various cane diseases with pathologists in the countries visited. Valuable information on the history, symptoms, cause, economic importance, transmission and control of foreign diseases has been accumulated as a result of these visits. Specimen material and photographs of most of the diseases studied were collected and placed on record. The information on foreign diseases resulting from foreign travel has been most helpful in diagnosing local diseases that resemble foreign ones.

F. A. G. Muir (Entomology Department) upon his return from British New Guinea in 1910 where he had been collecting parasites for the sugar-cane beetle borer, visited Fiji and was greatly impressed with the seriousness of Fiji disease. He brought back photographs and preserved specimens of the disease to the pathologists for study. These specimens are still in the Pathology museum. Lyon visited Fiji and Java during 1910-11 in order to investigate Fiji and sereh diseases, as well as other cane diseases in these two countries. Lyon discussed his findings on Fiji, sereh and other foreign diseases in his annual reports and pointed out that every effort should be made to exclude such diseases from Hawaii; he published his investigations on Fiji and sereh diseases in 1921. Histological and cytological studies of Fiji disease were conducted by Kunkel (1920-1923) on preserved material collected in Fiji by Lyon (1910). The presence of X-bodies or intracellular bodies in cells of affected plants were first described and illustrated by Lyon and later by Kunkel. They showed that the galls of Fiji disease appearing on the lower surface of the leaves originated in the phloem and that the disease must be looked upon as a phloem disease. It was from these studies that the effects of the disease on the cane plant were determined. A. F. Bell, Pathologist, Bureau of Sugar Experiment Stations, Queensland (1933), in a paper on the transmission of Fiji disease, states that, "...it is to his [Lyon's] published report that sugar-cane pathologists owe much of their knowledge of these two diseases [Fiji and sereh]."

During March 1911, 48 Hawaiian seedlings were sent to Fiji so that their relative resistance to Fiji disease might be determined. Cuttings of six of the newer outstanding commercial varieties (28-4291, 31-2484, 31-2806, 32-1063, 32-3575 and 32-8560) were sent to Queensland in 1939 so that their resistance to gumming, downy mildew and Fiji diseases might be established. The majority of the varieties were found to be highly susceptible to one or more of these dis-

eases. This information can only be obtained by testing the varieties in those countries where such diseases occur. Should a foreign disease gain entrance into Hawaii the resistance of locally grown varieties would have to be known before a satisfactory program for controlling it could be instituted.

Cobb had studied cane diseases, with special reference to gumming disease, in Australia before coming to the Station (1905). Lewton-Brain, prior to joining the department (1905), had investigated the diseases attacking sugar cane in the West Indies. Lyon has studied cane diseases in Fiji, Java, India, Australia, the Philippines, Egypt, Florida and Louisiana, Cuba, Barbados, Jamaica and Trinidad. Lee had become acquainted with the cane disease situation in the Philippines before joining the department (1923). Martin has studied cane diseases in Formosa, the Philippines, Java, Australia, Fiji, Cuba, Puerto Rico and Florida.

History and Control of Local Diseases

Diseases of Major Importance:

The incidence of a disease in any given locality is due to the susceptibility to disease of the variety grown and to environmental conditions which govern the development and spread of the causal organism. Sugar-cane varieties manifest different degrees of resistance to disease. A variety susceptible to a particular disease may be successfully grown in some regions because environmental conditions are not favorable for the development and spread of the parasite. Red stripe disease was of major importance on the Tip canes in the Kohala district, but in other localities it remained of minor importance.

The most effective control of any disease has been by the use of resistant varieties: for example, the control of Lahaina disease with H 109, the control of mosaic on Tip canes with D 1135, and the control of eye spot on H 109 with 32-8560. Varietal resistance to a disease may be determined by inoculating the varieties in question with the causal organism. Varieties have been inoculated with spores of the eye spot fungus in order to determine their degree of resistance to eye spot. Cane varieties have also been planted in areas where field conditions were extremely favorable for eye spot; the exposure to natural infection has been very effective for determining varietal resistance. These two methods have been used extensively for testing new varieties against eye spot. Similar methods have been applied in ascertaining varietal resistance to mosaic, root rot, brown stripe, leaf scald, and chlorotic streak diseases before spreading the varieties to large areas.

Disease control measures other than the substitution of resistant varieties have been practiced with considerable success. These methods have to do with the adjustment or modification of certain plantation practices, such as, time of planting, harvesting, irrigation and fertilization, soil amendments, the selection of healthy planting material, hot-water treatment of cane cuttings, roguing diseased plants, and weed control. These control measures have aided greatly in minimizing the severity of many diseases.

Sugar-cane breeding for disease resistance has been carried out in cooperation with the Genetics Department with the result that economic losses from serious diseases have been reduced to a minimum. A new variety may be quickly tested for its disease resistance but testing its commercial merits must extend over a period of several years.

It has been difficult to measure quantitatively the losses that have occurred

from certain diseases, such as eye spot and brown stripe. In such instances the losses have been estimated. However, with the systemic diseases such as mosaic, leaf scald, and chlorotic streak, replicated experiments have been installed by planting plots with healthy and diseased cuttings; the losses from each disease, expressed in sugar per acre, have been measured from the harvesting results.

A system for recording the degree of varietal resistance to disease was developed by Martin in 1926. The symbols used for expressing disease resistance follow:

++ Very highly resistant
+ Highly resistant
=+ Moderately resistant
= Average
=− Moderately susceptible
− Highly susceptible
−− Very highly susceptible

The relative degree of resistance to the major diseases of those varieties which have played the greater part in the Hawaiian sugar industry, as determined by field observations and varietal resistance tests, is presented in the accompanying table. In some instances no grading is given for certain varieties. The fact that these varieties have been exposed to natural infection and have remained free from disease indicates that the chances are they possess a high degree of resistance.

SUGAR-CANE VARIETIES AND THEIR RELATIVE DEGREE OF TOLERANCE TO THE MAJOR DISEASES

Variety	Eye Spot	Brown Stripe	Leaf Scald	Chlorotic Streak	Mosaic	Root Rot
Lahaina	−	−	−		−	−−
Yellow Caledonia	+	=−	=−	=	+	+
D 1135	=+	=−	+	=+	+	+
Yellow Tip	=+	=+	=−		−	
Striped Tip	=+	=+	=−		−	
Badila	+	=+	=−		+	+
H 109	−	−	=	=+	=	+
POJ 36	=	=−	++	=	++	+
POJ 2878	=−	=−	++	−	++	+
UD 1	−	−			+	
UD 50	+		=−		+	
H 8965	=−	=−	=−		=	+
Kohala 202	=+	=+	+		=−	
Uba	++	=+	+		+	+
26Q2873	=−	=+	+		+	
28-1234	=−	=+	+		+	
28-1864	−	+	=+		+	
28-2055	=+	=+	+		+	+
28-4291	+	=+	−	++	+	+
29-3859	=+	=+	−		+	
31-1389	++	−	=+	=	++	+
31-2484	+	=	++	=+	+	
31-2510	+	+	=−		+	+
31-2806	=	=+	+	−	+	+
32-1063	+	=+	+	=+	++	+
32-3575	+	=+	=+	=+	+	
32-8560	++	=+	+	=+	++	++

The leading variety fifty years ago was Lahaina. As shown in the above table, it was susceptible to all the major diseases. Today, the two leading varieties are 32-8560 and 32-1063, both of which are moderately-to-highly resistant to all the major diseases. The practice adopted many years ago of planting resistant varieties explains the scarcity of the diseases today (1945).

On the following pages the history, economic importance, control, and present status of the various diseases are presented. The most serious diseases of the industry are considered first, followed by a discussion on the minor diseases, physiological diseases (malnutrition), malgrowths, and miscellaneous injuries, each of which has been responsible for some economic field loss at one time or another.

Eye Spot: The first record of a disease attacking sugar cane in Hawaii was in 1854 by Lee and is discussed in the first paragraph of this paper. It is very likely that the acute losses referred to by Lee resulted from eye spot. A serious outbreak of eye spot occurred at Waialua in 1904-5. Cobb investigated the malady and identified the causal organism which already was known to cause considerable damage in other parts of the world. The disease no doubt existed in the Territory many years prior to 1905 and had been called top-rot, fire blight, and rust. Lewton-Brain described the disease in 1907. Lyon (1907-1914) made a critical study of eye spot and stated that its control would be effected by planting those varieties which possess both disease resistance and high sucrose qualities. These qualities were to be secured in new varieties by breeding. Larsen published his findings on eye spot in 1911 and 1912; he reproduced leaf symptoms by spraying spores of the eye spot fungus, *Helminthosporium sacchari* (van Breda de Haan) Butler, on leaves of healthy plants. The technique used in his inoculation tests was later adopted, with modifications, for determining the relative resistance of new varieties, wherein entire plants or cut stalks were sprayed with eye spot spores. During 1925 to 1929, the eye spot index or relative resistance of many varieties was determined by Lee, Martin and Barnum.

The relative varietal resistance has also been established by planting varieties in eye spot localities so that they would be exposed to natural infection. This work was conducted on plantations and substations where the disease was a serious problem.

A great deal of research work was carried out by Lee, Martin and Barnum during 1924 to 1928 on the control of eye spot with fungicidal dusts. The results showed that fungicides could not be used as a practical field control of eye spot.

Young seedlings growing in germination flats were inoculated with eye spot spores and segregated according to their degree of resistance by Martin and Carpenter (1924-1940). Many susceptible seedlings have been eliminated by this method. Determining the relative degree of resistance of new sugar-cane varieties before they were spread to large areas has accomplished much in the field control of the disease.

Eye spot is primarily a leaf disease. It is transmitted by the fungus spores and not by cane cuttings. It is most severe during the winter months. The factor most conducive for its spread is the presence of moisture on cane leaves, either as dews or light rains. The disease is first recognized by minute watery spots on the youngest leaves; these lesions soon enlarge into reddish centers with narrow mar-

gins of straw-colored tissue. Streaks or runners, sometimes two to three feet in length, extend from the lesion toward the leaf tip. The lesions and runners often coalesce, thus killing large areas of leaf tissue or the leaf spindle and finally the growing point (top rot). The greatest economic losses occur when top rot or the acute form of the disease develops.

Cane varieties making a rapid growth are more susceptible than those making a slower growth, as pointed out by Lyon (1909) and Larsen (1911) and later by Lee and Martin (1928). The younger the cane is as it enters the eye spot season the more susceptible it is to the disease, as demonstrated experimentally in 1928 by Martin who made monthly plantings of H 109 in an eye spot area.

The following points pertaining to eye spot have been investigated by different members of the department: (1) life history of the causal organism, (2) a study of isolates from different varieties and localities, (3) physiologic races of the organism, (4) histological studies dealing with the ingress and egress of the organism, (5) nature of resistance, (6) the nutrition of the cane plant in relation to the disease, and (7) air and soil temperatures and other environmental factors which influence the severity of the disease. The results of these studies have contributed greatly toward a better understanding of the disease and its control under field conditions.

Eye spot has been most serious on Kauai, Oahu, and Maui. Annual losses from eye spot have varied greatly; however, if a total of such losses could be accurately expressed in dollars and cents, the amount would be surprisingly large. Losses of 80 per cent or more have occurred in some instances in fields of H 109 and other susceptible varieties. Outstanding cane varieties, possessing both disease resistance and desirable commercial qualities, have been developed and tested by the Geneticists and Pathologists, respectively.

Eye spot under field conditions has been successfully controlled by planting resistant varieties—for example, the planting of 32-8560 in those areas where eye spot was a serious problem on H 109.

Root Rot or Lahaina Disease: The Lahaina variety of cane, also known as Otaheite and Bourbon, was grown at one time or another with marked success in almost every sugar-producing country, but sooner or later it failed completely. Hawaii proved to be no exception.

The failure of Lahaina cane (introduced in 1854 from Tahiti) caused greater concern to the Hawaiian sugar planters than any other single problem. Areas of yellowish and depressed growth in fields of Lahaina were reported on Hawaii as early as 1883 and soon thereafter the trouble appeared on the other Islands. Lahaina failure was quite widespread throughout the Territory by 1905 and serious sugar losses had occurred; during the next 10 years the severity of the disease greatly increased.

Affected plants manifested a yellowing and rolling of the leaves, a marked depression in growth, a rotting of the roots and were easily uprooted from the soil. In many areas a total loss resulted from the disease.

Investigations pertaining to the chemical or non-pathological factor or factors which might be responsible for the growth failure were started soon after the Experiment Station was organized in 1895. These studies were continued by the chemists and agriculturists for many years with special attention being given to

natural excesses or deficiencies of soluble salts in the soil (toxic compounds, poisons, etc.), soil acidity, soil amendments and varietal reactions under various environmental conditions. When the Pathology Department was organized in 1905, the cause and control of root rot became one of its major projects and remained so for the next 30 years, notwithstanding the fact that Lahaina was by 1913 being rapidly replaced with varieties resistant to Lahaina disease. Every member of the department has studied one or more phases of the problem.

The biological studies carried out by the pathologists dealt primarily with parasitic organisms causing root rots of cane. The pathologists from the very first carried out independently and cooperatively with members of other departments, many pot and field experiments in studying the effects on the disease of

Fig. 6. Top: H. L. Lyon and W. R. R. Potter.
Bottom: L. D. Larsen and A. T. Speare.

soil sterilization (by steam and chemicals), soil amendments, soil treatments with chemicals, fertilizers, and of diluting "sick soils" with "healthy soils."

The theory that Lahaina was "running out" or deteriorating was advanced in 1908, but was later renounced. The two fungi, *Ithyphallus coralloides* Cobb and *Clathrus trilobatus* Cobb, were regarded by Cobb (1906-7) to be directly associated with the cause of the growth failure. Lewton-Brain and Cobb in 1906 were of the opinion that *Marasmius sacchari* Wakker, the cause of Marasmius root rot, was responsible for the failure of Lahaina and to some extent Rose Bamboo. These, as well as other organisms studied later by Lyon and Larsen, were shown not to be directly associated with the cause of Lahaina disease.

Carpenter (1919-1921), conducted extensive studies relevant to the cause of root rot, and demonstrated by isolation and inoculation studies that the fungus, *Pythium graminicolum* Subramaniam, was responsible for root rot of Lahaina. In later studies (1927-1938), he showed in both pot and field experiments that the nutrition of the plant has a direct influence on the incidence of disease; resistant varieties (Yellow Caledonia, D 1135 and H 109) became susceptible to *Pythium* attack when excessive nitrogen was applied. A direct correlation was found to exist between the severity of the disease and increased amounts of nitrogen with Lahaina cane. Phosphate deficiency was found to be a contributing factor in root rot of D 1135 and other varieties.

For several years *Pythium* root rot became a serious problem in the propagation of sugar-cane seedlings. The use of sterilized soil, the disinfection of benches, and the application of a sanitary procedure throughout, as suggested by Carpenter (1932), brought about the control of this disease.

It was soon noted (1898) that Yellow Caledonia (introduced in 1884 from Australia) was much more resistant to root rot than Lahaina. Other resistant commercial varieties proved to be D 1135 (introduced in 1901 from Queensland), the Tip canes, H 109, P.O.J. 36 and P.O.J. 2878. The control of Lahaina disease was brought about only by planting such varieties in those localities where Lahaina failed. The development of H 109 by this Station in 1904 played a major role in the control of root rot; its commercial qualities and disease resistance were first demonstrated at Ewa (1913-15). The newer varieties, 32-1063 and 32-8560, have been found to be highly resistant to *Pythium* root rot.

Today root rot is of little or no economic importance with the present commercial varieties, whereas at one time this disease threatened the entire industry.

Mosaic: Mosaic disease, known as yellow stripe disease prior to 1920, was first recognized in Hawaii by Lyon in 1908 on certain of the H seedlings, Lahaina, the Tip canes and other varieties. He described the leaf symptoms as, "Light, watery patches on leaves." Lyon studied mosaic disease in Java in 1911 under the name Gele Strepenziekte (Yellow stripe disease) and concluded that the diseases in Hawaii and Java were identical. By 1912 mosaic was found to be very prevalent on Hawaii, Maui, and Oahu. Already marked differences in varietal resistance to the disease were apparent. On Hawaii, in 1917, 50 to 90 per cent of highly susceptible varieties were affected in some areas and serious damage resulted from mosaic in the Hamakua district in 1918. Mosaic is caused by a virus and is recognized chiefly by a mottling of the young leaves; it has a dwarfing effect on affected plants and growth is greatly depressed on very susceptible varieties and the plants

sometimes die. A mosaic survey completed by Doty in 1920 showed some 37,000 acres of cane to be affected, 4,700 of which were 10 to 50 per cent affected, while 2,400 acres were 60 to 100 per cent diseased. Losses from this disease alone were of considerable magnitude.

Lyon published a detailed account of the disease in 1921, describing its symptoms, listing varieties and their resistance, reporting the results of field experiments, and recommending measures for its control. Kunkel conducted extensive histological and cytological studies (1920-1923) on mosaic disease of cane and

Fig. 7. Top: R. E. Doty and E. L. Caum.
Bottom: C. W. Carpenter and L. O. Kunkel.

corn. He showed that cane mosaic is transmitted by the corn aphis and the expressed juice from diseased plants. He also showed that specific grasses, acting as weeds in the cane fields, harbor cane mosaic and the corn aphis and are a source of infection. From field experiments in which plots were planted with diseased cuttings, Kunkel reported mosaic losses to be much greater from some varieties (Striped Tip, 83%; Lahaina, 72%) than from others (H 109, 38%; D 1135, 42%).

The corn aphis lives normally on grasses and corn plants. When these plants become dry or are cut, the insects migrate to the cane plant. In so doing, they often transmit mosaic from diseased grasses to healthy cane plants. The disease is also transmitted by cuttings taken from diseased plants, as demonstrated in 1911 by Larsen. The disease developing from cuttings is known as primary infection.

Lee, Martin, Barnum, and Carpenter have investigated one or more of the following phases of mosaic: varietal susceptibility, new host plants, environmental factors influencing the disease, its mechanical transmission, plantation inspections and observations, and recommending and following up the measures for its field control.

Today, mosaic is a problem only in a few localities, whereas at one time it was of major importance on many plantations. Measures for controlling the disease were put into practice soon after its recognition in Hawaiian cane fields. The selection of planting material from healthy plants only and the planting of resistant varieties have been largely responsible for the scarcity of the disease at the present time. For example, the very susceptible Tip canes were replaced with D 1135, P.O.J. 36 and P.O.J. 2878; Yellow Caledonia, (being resistant but not tolerant), H 109, (moderately resistant), and Striped Mexican have replaced Lahaina and other susceptible varieties. More recently, the rapid spread of immune and highly resistant varieties has further reduced the incidence of the disease. Not a single case of mosaic disease has been recorded on 32-1063 or 32-8560. Roguing diseased plants, especially in spreading or seedling areas, has been practiced with success. The control of weeds which act as hosts for the vector and disease has aided greatly in minimizing sugar-cane mosaic. Those cultural practices which favor a rapid closing-in of the cane tend to check weed growth and reduce the corn aphis population in the fields.

Brown Stripe: Brown stripe was first identified in Hawaii in 1928 by Martin as a leaf disease distinct from eye spot. It is likely that brown stripe existed prior to 1928, inasmuch as brown linear leaf markings on various varieties were observed in 1927 by Martin and Barnum. Shortly after 1928, brown stripe became one of the major diseases on Kauai and Oahu.

The first morphological symptoms are minute watery leaf spots which soon assume an elongated shape with brownish-red centers surrounded by a yellowish halo. As the leaf spots mature they often coalesce and cause irregular dead areas of tissue. The older leaves manifest a prematurely dried appearance when the disease is severe. No runner extends from the lesion toward the leaf tip as with eye spot disease.

The disease is transmitted by spores of the fungus, *Cochliobolus stenospilus* (Carp.) M. & Y., the majority of which develop from lesions on old, dried leaves, as shown by Carpenter and Barnum. The perfect stage or ascospore stage of the

fungus was first observed and described in 1930 by Carpenter. Cultural studies of the causal organism have been carried out on different media and under varying environmental conditions.

Many field and laboratory studies have been conducted in relation to brown stripe control. The field studies were carried out on those plantations where the disease was most serious, with the cooperation of Station staff members of the Agriculture and Chemistry Departments. The chemical composition of the soil as well as of the plant was studied. It was found that the nutrition of the plant had a direct bearing on the incidence of the disease. Brown stripe was more severe on varieties growing in soils of a low fertility. The severity of the disease became less when additional fertilizers, particularly potash and phosphoric acid, were applied to areas where the disease was prevalent; more silica was found in leaves of healthy plants than in diseased plants. The majority of the field and pot studies were conducted on Kauai from 1930 to 1933 by Barnum.

The relative degree of resistance of sugar-cane varieties to brown stripe, based on field observations throughout the Territory by members of the Genetics and Pathology Departments, has been recorded. The tolerance of many varieties to the disease was summarized in 1930 by Barnum.

The incidence of brown stripe depends on the variety grown, existing climatic conditions, and the fertility of the soil. When the degree of infection is moderate to severe, the vitality of the plant is greatly lowered and sugar yields are reduced accordingly. Brown stripe rarely causes top rot or the death of the plants. In the field control of the disease careful consideration should be given to creating soil conditions as favorable as possible for normal cane growth. The substitution of resistant varieties has also been very effective for its control.

Chlorotic Streak: In 1929 R. K. Conant, Agriculturist, Olaa Sugar Company, submitted to the Pathology Department specimen material of leaves of P.O.J. 36 exhibiting long, irregular, chlorotic streaks, some of which extended the full length of the leaves. These leaf markings were recognized as being identical to that of the "fourth disease" in Java and of "pseudo-scald" in Australia; the disease was studied by Martin in these countries in 1929. The name "chlorotic streak" was given the disease in Hawaii, since this terminology was more descriptive than the Java or Australian names.

A plantation survey made in 1929 showed chlorotic streak to be present on five other plantations on Hawaii and on two Oahu plantations. It was later found to a very limited extent on Kauai and Maui (1931 and 1932). Conant recalled having observed the disease during the summer of 1927 on P.O.J. 36 at Olaa.

Chlorotic streak is recognized by the presence of one or more long, irregular, yellowish or chlorotic streaks, especially on the older leaves. The margins of the streaks are irregular or wavy in outline. In the older lesions the leaf tissue often dies. Reddened vascular bundles are usually found at the nodes of an affected stalk.

Many attempts have been made by Carpenter, Barnum and Martin to isolate a causal organism from diseased leaf and stalk material. A number of bacteria and a few fungi have been isolated, but when inoculated into healthy canes they failed to produce symptoms of disease. Infusions and plant extracts prepared from diseased plants failed to produce symptoms of chlorotic streak when inoculated into healthy stalks of susceptible varieties. Various artificial methods

often used for transmitting plant diseases were tried, but with negative results. Experiments dealing with insect transmission with the sugar-cane leaf hopper, the pink sugar-cane mealy bug, the onion thrips, the sugar-cane stalk mite, and the green leaf hopper have yielded negative results in each case.

Histological investigations of chlorotic streak were made by Weller. In 1937 he reported the presence of a plasmodium type of organism in diseased leaf and stalk tissues.

In 1940 Carpenter reported an intracellular parasite associated with chlorotic streak. The presence of the Chytrid, an aquatic type of fungus, was of considerable interest as a possible cause of the disease.

Chlorotic streak is transmitted by cane cuttings. Evidence that secondary infection occurs was shown when a number of the 1932 seedlings, germinated at the Experiment Station, were planted at Kailua. These seedlings remained healthy during the first six months of their growth, but shortly thereafter a number of the seedlings contracted the disease. Other examples of secondary infection are on record. It was demonstrated by Martin and Conant in 1930 that the disease was controlled by the hot-water treatment (52°C. for 20 minutes). Losses from the disease have been measured in field experiments by harvesting replicated tests planted with healthy, diseased, and treated (hot water) diseased cuttings. Sugar yields from the diseased plots were from 13 to 30 per cent less than from the healthy and treated diseased plots.

The disease, from field tests and observations in Hawaii and elsewhere, is more prevalent in localities where rainfall is heavy and in low-lying and poorly-drained soils. The field and nutrient-solution studies indicate that the disease is most severe in areas where the soil is deficient in potassium.

Chlorotic streak now occurs on each Island, but is most prevalent on Hawaii. The disease has best been controlled by planting only healthy material and subjecting any questionable or diseased planting material to the hot-water treatment. Varietal resistance tests have been carried out wherein the standard and newer seedlings were exposed to natural infection; the degree of resistance was recorded at harvest and such information given to the plantations. The use of resistant varieties has greatly aided in reducing the incidence of the disease to a satisfactory minimum in many localities. Chlorotic streak is the only important disease to which the new standard varieties 32-8560 and 32-1063 are susceptible.

Leaf Scald: Leaf scald, one of the major cane diseases of the world, was first reported in Hawaii in 1930 by Martin, Carpenter and Weller, who carried out the various field and laboratory studies discussed below. There is some evidence indicating that the disease existed to a small degree at least 10 years prior to 1931. The original studies were made on certain of the Manoa seedlings on Hawaii; later leaf scald was found on Kauai (1931), Maui (1932) and Oahu (1931 and 1935).

Leaf scald is caused by the bacterium, *Phytomonas albilineans* (Ashby) Magrou. It affects the leaves and stalks. The earliest symptoms are recognized by the presence of elongated, narrow, white stripes on the leaf blade and sheath, side shoot development (lalas), and an internal reddish discoloration of the bundles, especially at the nodes and near the growing point; this is the chronic phase. In the acute phase, affected plants suddenly wilt during periods of dry weather or when the cane approaches maturity.

The greatest losses occur from the acute phase since the affected stalks frequently die. The cane is not generally killed in the chronic phase. In either case, cane growth is retarded and the juice quality is lowered depending on the severity of the disease.

Numerous studies have been conducted in the field and laboratory in order to establish more effective measures for its control. The disease is systemic and is readily transmitted from one field, locality, or country, to another by diseased cuttings. It is also spread by cane knives.

Field studies (1933-1934) in cooperation with C. E. Pemberton (Entomology Department) demonstrated that grasshoppers and leaf hoppers do not play an important role in the transmission of the disease. The causal organism is not capable of remaining in the soil for long periods and later causing infection. The cultural characteristics of the pathogen and the histology of the disease were investigated.

The disease may also be transmitted by inoculating cane plants or cuttings with the leaf scald organism, a method which has been used to advantage for determining the relative resistance of varieties to the disease. The inoculated cuttings were planted in a locality where conditions favored the disease. The reaction of each variety to the disease was recorded during the growth of the cane and a final grading was given each variety as to its susceptibility when the test was harvested. Many hundreds of varieties including the standard and newer canes have been tested against leaf scald since 1930. These varietal resistance tests and other field studies have been conducted chiefly at Olaa.

The severity of the disease is governed by existing evironmental conditions and the susceptibility of the variety grown. The incidence of the disease is associated with the nutrition of the cane plant. When the cane growth is retarded as a result of low soil fertility, drought, or maturity, the disease is much more severe. The hot-water treatment (52°C. for 20 minutes) resulted in a partial control (60 to 80 per cent) of leaf scald.

The substitution of resistant varieties has been highly effective for controlling leaf scald. The selection of healthy cuttings for planting material has aided in reducing its spread. Roguing diseased plants has been practiced with success especially for maintaining nurseries and seedling areas free from the disease. During the past 15 years, or since leaf scald was first recorded in 1930, very satisfactory progress has been made by the plantations in controlling the disease.

Pokkah Boeng: Pokkah boeng disease was first studied in Java (1896) but its cause was not clearly demonstrated until 1927 when it became epiphytotic with the spread of P.O.J. 2878 in Java. The disease is caused by the fungus, *Gibberella fungikuroi* (Saw) Wr. It is transmitted chiefly by the spores of the fungus and develops most rapidly during hot, moist weather. It also occurs in Australia, Cuba, and other countries.

During 1928 the variety P.O.J. 2878 developed pokkah boeng disease while under quarantine at the Pathology Plot. Field inspections showed that the disease was also present on certain other canes but only in a very inconspicuous form. It was later established that pokkah boeng had been observed on seedlings almost a year prior to the introduction of P.O.J. 2878.

Lee reported on pokkah boeng and twisted top of sugar cane in 1928, pointing

out that the latter is a mechanical difficulty and is non-infectious. Carpenter investigated pokkah boeng disease in 1928 and 1929 and demonstrated its cause and infectious nature by isolation and inoculation studies. He produced typical symptoms of pokkah boeng on rapidly growing cane (H 146) by inoculating the spindles with spores of a Fusarium which he isolated from diseased cane and identified as *F. moniliforme* Sheld. var. *subglutinans* Wr. et Rg. Field inspections were made as soon as the disease became known in Hawaii in order to determine its occurrence and seriousness on the plantations.

The name pokkah boeng is a Javanese expression signifying damaged or malformed top. The outstanding symptoms of the disease are the development of chlorotic areas and a narrowing or distortion toward the base of the young leaves, a distortion of the spindle, which is sometimes killed, the presence of discolored bundles in the stalk near the growing point, the development of external, ladder-like, stalk lesions, and a deformed growth of the stalk.

Small outbreaks of pokkah boeng have occurred on several of the commercial varieties during periods of kona weather, but in each case the injury was more or less temporary, and the affected plants usually recovered. On a number of seedlings the disease has caused considerable damage resulting in top rot and badly distorted growth. Seedlings severely affected by the disease have been discarded in a few instances.

During 1928 and shortly thereafter, the pathologists were greatly concerned about pokkah boeng since its potential damage under local conditions could not be predicted. The fact that existing climatic conditions are not favorable for the rapid development of the causal organism explains the insignificant role the disease has played in the local industry. In Java, counts in certain fields of P.O.J. 2878 showed that 10 to 15 per cent of the stalks had died from pokkah boeng.

Marasmius Root Rot: Lewton-Brain, in 1905, described Marasmius root rot and stated it to be responsible for the failure of Lahaina and Rose Bamboo canes. Cobb, in 1906, reported that the Marasmius fungus in Hawaii exhibited certain peculiar characters which separated it from those described elsewhere. Because of these differences he named the organism, *Marasmius sacchari* Wakker var. *Hawaiiensis* Cobb. The disease has also been studied by other members of the Department. Today the fungus is considered as a weak parasite and attacks cane that is in a weakened or poor growing condition due to other causes. It was later demonstrated that Marasmius root rot was not responsible for Lahaina failure. The disease has been reported in almost every country where sugar cane is grown and is now included in the group of minor diseases.

Plants attacked by Marasmius root rot are depressed in growth; the leaves become yellow and dry prematurely. The underground portions of affected stalks show a definite reddish-brown internal rot; at times a soft rot develops on the root bands near the surface of the soil. The roots of the diseased plants become brownish-red in color and the growing points are killed. Plants seriously affected are easily uprooted from the soil. At the base of diseased plants, toadstools up to one and one half inches in diameter are frequently found in the early morning following rainy weather. These delicate grayish-white structures are the fruiting bodies of the fungus and give rise to spores by which the disease is transmitted

to new areas. The fungus develops in the field on old cane stubble and cane trash and under suitable conditions attacks cane roots.

Fig. 8. Top: H. A. Lee and J. P. Martin.
Bottom: C. C. Barnum and D. M. Weller.

Large economic losses from Marasmius root rot were reported in the early records. Marasmius root rot has been rarely found affecting sugar cane during the past 25 years. In instances where the disease was thought to be causing serious damage, control has been prescribed through the use of planting resistant varieties, removing old cane stubble from diseased fields, plowing and cultivating frequently, and creating optimum conditions for cane growth.

Ring Spot: This disease was first studied in 1906 by Cobb and later reported upon by him in 1909. Larsen also studied ring spot, described the disease in detail in 1913 and discussed various fungi which he found associated with it. Since these first studies, various staff members have frequently commented on the disease, following their plantation inspections.

Ring spot is a disease of long standing and now occurs in almost every country where sugar cane is grown. The fungus *Leptosphaeria sacchari* van Breda de Haan, has been generally accepted as the cause of ring spot; however, some investigators believe it to be of only secondary importance. The disease has been considered of minor importance in Hawaii and elsewhere. This leaf disease is characterized by irregular, small, light greenish-purple spots which soon enlarge and turn brown-to-black with straw-colored centers. The disease is confined chiefly to the older leaves. A few seedlings have been seriously attacked but these canes never have become commercially important.

Red Rot: Lewton-Brain began to study red rot shortly after he joined the Division (1905) and published a detailed account of the disease in 1908. At one time red rot in the West Indies was thought to be a possible factor in root diseases but subsequent studies showed it to be parasitic only on the stalks and leaves. The disease has caused serious losses in Australia, India, and Louisiana. Since Lewton-Brain's contributions, other members of the department have investigated some phase of the disease, all of which have resulted in a better understanding of red rot under local conditions.

The disease may attack newly planted cuttings or stalks and leaves of growing cane. Plants severely affected may show a wilting of the leaves, a loss of normal green color, or a premature drying of the leaves; in some cases the plants die. Affected stalks, or cuttings, manifest a reddish discoloration which may extend throughout one or more internodes. The red rot fungus, *Physalospora tucumanensis* Speg. (*Colletotrichum falcatum* Went), usually enters the plant through mechanical or insect injuries. There is little evidence that the disease has caused serious economic losses to growing cane in Hawaii.

If fields are planted during periods of cool wet weather, the cuttings may become affected and poor germination results. Treating the ends of cuttings with fungicides such as Bordeaux (as shown by Cobb in 1905), ceresan, and semesan has greatly minimized the severity of the disease. Red rot may also attack cane that is allowed to stand for several days after harvesting. Varieties show a wide range of tolerance to the disease. The majority of the commercial canes have proved commercially resistant to red rot.

Pineapple Disease: In 1906 Cobb described pineapple disease and stated that the greatest amount of damage occurred in newly planted cuttings, especially during periods of wet weather. The disease has been studied since 1906 and reported in the fields from time to time by other members of the department.

This particular malady was named pineapple disease because the odor of affected cane tissues resembles that of the pineapple. The disease is caused by the fungus, *Ceratostomella paradoxa* (de Seynes) Dade, and is transmitted by spores of the pathogen and, to a lesser degree, by cane cuttings. The fungus also attacks pineapple and banana plants.

Pineapple disease affects primarily cane cuttings and cane stalks. Leaves of

diseased plants may at times show signs of wilt. The causal organism is chiefly a wound parasite. Affected tissues of the stalks assume a reddish color and later take on a sooty appearance.

The disease has caused some losses in fields of standing cane in a few localized areas and rather marked losses in newly planted cuttings. The treatment of cuttings with fungicides prior to planting has been highly effective for controlling pineapple disease, red rot and other diseases causing stalk rots.

Iliau: The first report of iliau disease was by Cobb in 1906. He described the symptoms of the disease and concluded that it appeared to be caused by certain Lepidopterous larvae which were generally found in affected shoots. In 1910 and 1912, Lyon published his complete studies of the disease giving its cause, description, economic importance, transmission, and control. Lyon found the cause of iliau to be a new and undescribed species of *Melanconium* and named the fungus, *M. iliau* Lyon. In later studies he found the perfect stage of the organism and designated it as *Gnomonia iliau* Lyon. Cobb apparently based his conclusions on advanced stages of the disease since insect larvae of various kinds frequently occur in cane plants killed by iliau, or other causes.

Iliau is a Hawaiian word signifying "tight skin" or "hide bound" and is highly descriptive of the disease since the most conspicuous symptom is the binding of the leaf sheath into a firm, tight case. Prior to 1915, losses from iliau were at times of major importance but since this date losses have been gradually reduced to a point where they are of little significance. Today cases of iliau are rare. Creating better growing conditions combined with the faster growing varieties have been largely responsible for the control of iliau.

Rind Disease: Rind disease in Hawaii has been studied and reported upon by Cobb (1905), Lewton-Brain (1907), Lyon (1910), and Larsen (1910). Rind disease was thought at one time to cause considerable damage to growing cane. This view, however, was not substantiated in later (1910) investigations. In Barbados and other islands in the West Indies, it was stated that Lahaina cane failed (1895) as the result of rind disease; the failure of Lahaina is no longer attributed to the disease.

Rind disease occurs in almost every country where sugar cane is grown and today is considered of minor importance. It is caused by the fungus, *Pleocyta sacchari* (Mass.) Petr. and Syd. As the name implies the disease affects primarily the rind of the cane. It is also reported that leaves and cane cuttings are attacked. Leaf symptoms in Hawaii are rare. The disease develops most rapidly on dead or dying cane but especially on stalks which have been cut and allowed to remain in the field for several days or more. The rind becomes discolored, somewhat roughened, and numerous small eruptions or pustules develop on the affected areas. Masses of spores in the form of hair-like bodies develop from the pustules on the rind. The internal stalk tissue is of a red-to-reddish-brown color and the internodes are shrunken. Since the disease has been of such little economic importance, no measures of control have been worked out.

Pahala Blight: For many years prior to 1905 sugar cane in specific areas at Pahala developed a leaf chlorosis which at that time was not known to occur in other parts of the Islands. Cobb (1906) first described the condition as the "leaf-

splitting disease," and attributed the cause to the so-called leaf-splitting fungus, *Mycosphaerella striatiformans* Cobb. This organism was later shown to be of secondary importance. About 1906 this type of chlorosis was named Pahala blight. Lyon investigated Pahala blight and stated in 1909 that it was caused by some abnormal soil condition. In 1919-1920, he described Pahala blight and showed that affected plants recovered following applications of large amounts of iron sulphate or organic matter.

W. T. McGeorge of the Chemistry Department studied Pahala blight very extensively and concluded in 1926 that it was the result of a physiological or nutritional disturbance induced by soil conditions. He demonstrated that applications of sulphur to the soil corrected the disease. Lee and McHargue (1928) investigated the effect of a manganese deficiency in sugar cane and its relation to Pahala blight. According to F. E. Hance (Chemistry Department) pyrolusite, a crude manganese dioxide, applied to the soils directly or in the "fertilizer mix" controlled Pahala blight at Olaa. Moir (1930) reported that small amounts of manganese were necessary for normal cane growth in certain fields at Olaa. L. E. Davis (1931, Chemistry Department) and Martin (1931,1934) produced symptoms of Pahala blight in water-culture solutions and showed that manganese in small amounts was essential for normal cane growth.

Pahala blight at one time caused serious losses at Pahala. It has been observed on all of the Islands but in most instances has been of minor importance. The leaf tissue between the large bundles becomes pale and later shows evidence of yellowish-green-to-whitish longitudinal stripes alternating with the normal green color. In advanced stages, necrotic reddish-brown regions appear in the chlorotic stripes and cause stripes of dead and dry tissue, which frequently split longitudinally. The application of manganese to the soil with the fertilizer has given an excellent control of the disease.

Red Stripe: A leaf disease of the Tip canes in the Kohala district was first described in 1922 by Lyon who stated that the malady was caused by parasitic bacteria. In 1924 Lee and W. C. Jennings also described red stripe disease and in direct inoculation studies showed it to be caused by bacteria. Lee and Martin demonstrated in 1925 by isolation and inoculation studies that red stripe was caused by a specific bacterium and named the pathogen, *Phytomonas rubrilineans* Lee *et al.* The morphological and cultural characteristics of the pathogen were studied in detail by Purdy, Lee, and Martin (1925).

Histological studies of the disease were conducted by Lee and Weller (1925). The majority of the field studies were carried out in the Kohala district by Barnum (1924-5). The organism may remain alive in the soil for 32 days, but during this time there is a great reduction in numbers of individuals. The relative resistance of a number of varieties has been determined in the field by artificial inoculations and by exposing varieties to natural infection.

Red Stripe has been confined almost entirely to the Kohala district, although it has been observed to a very limited degree on each of the other Islands. It is primarily a leaf disease but in advanced cases it affects the spindle, growing point, and stalk, and sometimes kills these plant parts. The main characteristic of the disease is the presence of long, well-defined narrow red-to-maroon-colored stripes on the leaf. The disease is most severe during the winter months at which time the bacteria form in small droplets on the leaf surfaces and are transmitted from

one plant to another during wind storms. The organism may also be spread by mechanical means. Red stripe is not transmitted by cane cuttings nor is it readily transmitted by cane knives.

Reductions in cane yields ranging as high as 15 per cent have occurred following a heavy degree of infection. Field observations showed the disease to be most serious on young ratoons, at the higher elevations, especially when the fields were harvested during the winter months.

An early planting and harvesting program has aided materially in lessening the severity of the disease. The substitution of resistant varieties has been responsible for the control of the disease. The present commercial varieties are rarely affected. Today red stripe is of minor importance.

Chlorosis: Various non-infectious types of chlorosis have always been present to a greater or lesser degree in the fields and have received attention by various staff members. The more common types are:

Banded chlorosis, also known as sectional and cold chlorosis, is recognized by irregular horizontal bands of chlorotic-to-white tissue extending across the leaf. It is due to low temperatures, as shown by Lee in 1927; the severity of injury varies directly with the degree of coldness. Some varieties are more sensitive to banded chlorosis than others. This type of chlorosis has not caused serious damage to cane in Hawaii.

Chlorotic leaf blotch produces one or more irregular chlorotic blotches at the base of the leaf blade and is particularly common on Yellow Caledonia, P.O.J. 2878, Yellow Tip and Kohala 202. It has been of minor importance. The cause of chlorotic leaf blotch is unknown.

Limestone chlorosis is confined to calcareous soils or soils containing large amounts of coral. A deficiency of iron often exists in such soils, and much of the iron that is present is unavailable to the cane plant. The youngest leaves become pale, followed by the development of chlorotic-to-white stripes extending the full length of the leaf. The leaves may be entirely white in advanced stages, growth ceases, and the plants frequently die. Limestone chlorosis may be controlled by spraying plants with a solution of iron sulphate or by soil amendments which make the soil more acid. In some instances economic losses from limestone chlorosis have been moderate to severe in localized areas.

Ratoon chlorosis develops on young ratoon cane but after a short time the plants ordinarily regain their normal green color. The symptoms are similar to those of limestone chlorosis. When severe, plant growth is greatly depressed and if the condition is not corrected the plants sometimes die. Economic losses at times have been of major importance from ratoon chlorosis. Large areas on some plantations have been sprayed in order to maintain economic losses at a minimum.

Spraying affected plants with a solution of iron sulphate has been practiced with good success for controlling ratoon chlorosis which seems to be caused by a temporary iron deficiency. McGeorge of the Chemistry Department (1926) and members of the Pathology Department have investigated ratoon chlorosis.

Minor Diseases: Sugar-cane diseases are usually classified as of major or minor importance. Some diseases always remain of minor importance while others be-

come epiphytotic and assume major importance, depending upon the prevalence of the pathogen, the susceptibility of the variety grown to a specific disease, and existing environmental conditions. Every disease retards normal cane growth to some extent. If economic losses resulting from those diseases which have always been considered of minor importance could be accurately expressed in monetary terms, the total amount would be of a considerable magnitude. Some of the minor diseases are briefly discussed.

Leaf freckle (cause unknown) was discussed by Larsen in 1910, but in all probability it existed many years prior to this date. Various members of the department have studied this particular leaf disease. It produces small chlorotic spots with reddish centers; the older lesions are surrounded by a yellowish areola and are very conspicuous on the green leaves. The disease is most pronounced on the upper surfaces of the older leaves and when severe entire fields may take on a rusty-red color. Canes growing at the higher elevations where low temperatures occur are more susceptible than canes at the lower elevations. Yellow Caledonia, D 1135, Uba, a number of the UD seedlings, and other varieties have proved to be sensitive to leaf freckle. This leaf spotting occurs on all Islands and is usually associated with retarded cane growth.

Leaf buckle is caused by the wind bending the cane leaves in the opposite direction to their normal curvature and is recognized by whitish spots, quite evenly spaced, along the midrib. Leaf buckle is more prevalent in localities subject to strong winds, but has been of little economic importance.

Leaf fleck (cause unknown) produces short elongated chlorotic markings over the entire leaf. Old lesions sometimes show reddish or necrotic centers. Leaf fleck seldom affects the standard varieties but it is frequently observed on certain seedlings.

Midrib blotch (cause unknown) is confined to the midrib of the leaf. Irregular chlorotic-to-yellowish blotches, often several inches in length, develop on the midrib of young plants. This particular leaf marking was first recorded in 1933. To date it has been of very minor significance.

Phyllosticta spot was first described by Caum in 1919, when it became somewhat serious on several seedlings of the H 5900 group. It is caused by the fungus, *Phyllosticta Hawaiiensis* Caum, which produces irregularly shaped straw-colored spots on the leaf sheath, at or near the point of attachment to the stalk. On susceptible varieties, the rind below the affected leaf sheath is often attacked. The disease is transmitted by spores of the causal organism. *Phyllosticta* spot has never caused any appreciable losses on the commercial varieties.

Sclerotial disease, also known as red rot of the leaf sheath, is caused by the fungus, *Sclerotium rolfsii* Sacc., and was first described in Hawaii by Lyon in 1909 and again in 1920 by Caum. The disease occurs in almost every sugar-cane country. It affects primarily the leaf sheaths, binding or cementing them together and to the stalk, somewhat in the same manner as iliau. The spots on the leaf sheaths are irregular and red-to-reddish-brown in color; the tissue between the veins soon disintegrates thus leaving the vascular bundles exposed. Some seedlings have been moderately to severely affected upon different occasions but the disease has never seriously attacked the commercial varieties.

Sooty mold produces a black, sooty deposit on the cane leaves and is associated with outbreaks of such insects as the leaf hopper, the cane aphis, and the mealy bug. During the severe outbreaks of the leaf hopper (1903-1905) many fields assumed a blackened condition.

The mold, (*Capnodium* spp.), grows in the honeydew secreted by insects on the cane leaves; this growth is largely superficial but, nevertheless, it interferes with certain physiological processes taking place in the leaf, thus causing chlorosis and depressed cane growth. Heavy rains aid in washing the honeydew, which nourishes the mold, from the leaves. The severity of sooty mold varies directly with the seriousness of the insect infestation. Sooty mold in recent years has not been conspicuous in Hawaii because of the successful biological control of the various sugar-cane leaf insects.

Internal stalk necrosis was first recorded in 1931 and now occurs on each Island. Preserved specimen material of Striped Tip and Yellow Caledonia collected at Paauilo by Larsen in 1911 and still in the Pathology museum, exhibits symptoms similar to those of the disease.

The symptoms of internal stalk necrosis are: a premature yellowing of the older leaves combined with orange-yellowish midribs, depressed growth, and an internal browning of the tissues of the internode.

Microscopical, bacteriological, and histological studies of diseased tissues have revealed no definite organism associated with the disease. The investigations to date suggest that the cause of the disease is physiological rather than pathological in nature.

Physiological Diseases—Malnutrition: Since the beginning of the industry, sugar-cane varieties in localized areas have failed to make a satisfactory growth as a result of unfavorable environmental factors. These physiological disturbances are spoken of as non-parasitic or physiological diseases. The symptoms of such diseases are often similar to those caused by parasitic organisms. The more important environmental factors which have been responsible for an abnormal growth are: excesses of soluble salts in the soil, unfavorable water relations, such as drought, water-logging and poor drainage, abnormally high and low air temperatures, a deficiency in the soil of one or more of those elements essential for normal plant growth, insufficient light, improper air conditions, such as excessive winds, and poor physical qualities of the soil. The principal growth failure problems in which the pathologists have taken a very active part will be discussed.

Lahaina disease, now known as *Pythium* root rot and discussed elsewhere in this paper, received more intensive study by the entire Station than any other individual problem. The environmental factors listed above and their influence on Lahaina failure have been carefully investigated; certain of these factors were found to aggravate greatly the severity of the disease. Numerous field and pot experiments were conducted in studying the effect of soil sterilization, soil amendments, soil treatments with chemicals and fertilizers on the disease, as well as diluting "healthy soils" with "sick soils" and vice versa. The effect of fallowing, green manuring, and planting catch crops for nematode control were also studied. The control of Lahaina failure was finally brought about by planting resistant varieties in those localities where Lahaina failed.

Maui growth failure, as the name implies, has been confined chiefly to Maui, although a similar trouble has been recorded on Kauai and Oahu, but only to a very limited extent. The first reference to this particular type of growth failure was in 1925. Cane varieties, especially H 109, completely failed in small localized areas. There is no evidence that these areas have increased in size. Cane growth is greatly retarded and one or more wide chlorotic stripes usually develop on the leaves. The stalks of affected plants are small in diameter, taper rapidly at the growing point, and are easily pulled out of the soil. The older leaves are more or less severely affected with brown stripe disease.

A great number of pot and field experiments have been conducted by members of the plantations and of this Station. The pathologists devoted particular attention to biological factors which might be responsible for the growth failure, but no pathogenic organism was found to be associated with the diseased condition. The physical and chemical qualities of the soil in these areas have been studied by the agriculturists and chemists. The exact cause of Maui growth failure has not been established.

Malnutrition, or a deficiency of one or more of the essential elements in the soil, has been in many instances the limiting factor for cane growth. The application of fertilizers, the kind and amount depending on the natural fertility of the soil, has been of paramount importance in relation to the growth and productiveness of a given variety. Any number of examples might be cited where the cane plant has responded to increased applications of nitrogen, potassium, or phosphorus. In some areas a lack of available manganese (Pahala blight) or iron was responsible for depressed cane growth; the addition of such elements to the soil corrected these physiological diseases.

Deficiency symptoms of boron, calcium, iron, magnesium, manganese, nitrogen, phosphorus, potassium, and sulfur on H 109, Yellow Caledonia, D 1135, P.O.J. 2878, 32-1063, 32-8560, and certain other varieties have been induced and studied in water cultures by Martin (1932-1945). From these studies it was possible to become better acquainted with the symptoms of the various nutritional deficiencies as they occur under field conditions. It is of interest to note that symptoms of boron, calcium, magnesium, and sulfur deficiency have not been observed on cane in the fields.

Other growth-failure problems in which members of the department carried out special pathological investigations and cooperative studies with members of the respective plantations and other Station departments, were at Grove Farm, Hamakua, Honokaa, Kilauea, and Olowalu.

Malgrowths: Sugar cane, like any other plant, infrequently develops peculiar outgrowths, the causes of which in some instances are unknown. The more common malgrowths have been described and illustrated by Lyon in 1910, 1926 and 1927, and Martin in 1932 and 1938. A number of specimens of such abnormal growths collected since 1910 are in the Pathology museum. In general, these abnormalities have not seriously affected the commercial varieties.

Stem galls were first studied and reported by Lyon in 1910. These proliferations have been found on a large number of varieties, including most of the commercial varieties on which they have been of minor importance. Stem galls

were extremely common on several of the Uba x D 1135 hybrids. The galls develop both on the nodes and internodes and later may give rise to adventitious buds which in turn develop into leafy shoots. Repeated contact plantings of galled and healthy canes indicated the condition to be non-contagious. Lee (1927) found that plant juices expressed from gall tissues and inoculated into healthy plants yielded negative results. Isolation and inoculation studies by Barnum (1926) failed to reveal any pathogenic organism associated with stem galls.

Sugar-cane insects, especially the sugar-cane stalk mite, *Tarsonemus spinipes*, have been investigated by Lyon (1926), Pemberton (1927), and Carpenter (1932-34) as contributing factors in the transmission of stem galls. It was felt that the stalk mite, as well as other insects, might stimulate or incite, during their feeding, certain embryonic cells to develop into stem galls.

Martin in 1936 and 1944 showed that insect extracts prepared from the green leaf hopper, *Draeculacephala* sp., the corn leaf hopper, *Peregrinus maidis*, the common ant, *Pheidole megacephala*, and the carpenter ant, *Camponotus maculatus*, respectively, when injected into healthy plants of H 109, P.O.J. 2878, and 32-8560 produced stem galls which were identical in every respect to those occurring naturally in the fields. The fact that stem galls developed after injection of insect extracts, which were sterilized at 15 pounds steam pressure for 20 minutes, suggested that the cause of stem galls is chemical rather than biological in nature. Stem galls have received the greatest amount of study of the various abnormal growths.

Enlarged buds and stalks have developed, at times, from apparently normal plants; one of the first reports pertaining to this condition was on Yellow Caledonia in 1905 by Cobb. Cuttings from such material have given rise to only normal or slightly inferior plants; the stimulated effect was not carried over by the cuttings. Multiple buds on cane stalks of H 109 and other varieties have been recorded. Bifurcated stalks were somewhat common on the variety Co. 213; this type of growth has also been noted on other varieties. Stalks manifesting zigzag and spiral joints, and sporadic elongation of internodes have been observed and studied.

Aerial or adventitious root development at the nodes well above the ground has been of common occurrence on some varieties. This condition was at one time associated with potash deficiency. Aerial rooting often develops in wet localities, especially on varieties where the dry-leaf sheaths adhere to the stalk. One symptom of sereh disease in Java is the copious root development at the nodes. The varieties Yellow Caledonia and D 1135, in 1910, and Maikoiko, in 1933, showed a definite rooting at the nodes. Normal growth resulted from cuttings of these varieties. After studying these cases Lyon (1910) and Martin (1933) concluded that the canes were not affected with sereh disease.

Bunch top, resulting from the growing point dividing into many buds which develop into individual shoots, is more often observed following the tasseling season. Some varieties are more sensitive to bunch top than others.

Knife cut occurring usually on the internode immediately above the bud has been an extremely interesting abnormality for many years. The disappearance of the tissue, leaving a symmetrical cut, suggests that it was carefully removed

with a sharp pen knife. Narrow, uniform cuts completely girdling the stalk have also been observed; the stalk at this point is greatly weakened and easily broken.

Tangle top, a non-infectious condition, has been more common in dry districts. The leaves become tangled or twisted and may remain so throughout the growth of the plant. Lee, in 1928, produced tangle top by wrapping the young leaf spindle with friction tape and also by bending the leaf spindle. In each case the mechanical injury restricted normal development of the new leaves. Tangle top, when severe, has been known to kill individual cane plants.

Importance of Miscellaneous Injuries in the Disease Problem

The sugar-cane plant has always been exposed to various animal, chemical, elemental, and mechanical injuries during its growth. Some of these injuries have been responsible for reduced sugar yields, under specific conditions. Such injuries often permit the entrance of parasitic organisms and produce disease-like symptoms on the plant.

Animal Injuries:

Insects: The anomala beetle, *Anomala orientalis* (Waterh.), feeds in the grub stage on the underground portion of the cane plant. The grub of the beetle borer, *Rhabdoscelus obscurus* (Boisd.), causes extensive injury to the cane stalk. The sugar-cane leaf hopper, *Perkinsiella saccharicida* Kirk., lays its eggs in the cane stalk and the midrib of the leaf. In so doing, these insects cause injuries to specific plant parts through which fungi and bacteria gain entrance to the plant and cause disease.

Sooty mold may be somewhat common following heavy infestations of the cane aphis, *Aphis sacchari* Zehnt., and the leaf hopper. The corn aphis, *Aphis maidis*, transmits mosaic disease from grasses to cane (see mosaic disease). Thrips, *Thrips saccharoni* Moulton, feed largely on leaves yet unrolled and cause a mottling or "silvering" of the leaves that somewhat resembles the leaf symptoms of mosaic disease. The Java sugar-cane leaf mite, *Tetranychus exsiccator* Zehnt., as a result of its feeding, causes a chlorotic condition on the leaf. When the injury is severe the leaves turn reddish brown with a premature drying of edges and tips.

Soil-inhabiting animals: A certain amount of injury to the roots, especially to the growing point, has been caused by nematodes [two species, *Tylenchus similis* Cobb and *Heterodera marioni* (Cornu)], centipedes, snails, and springtails. Certain of these injuries have prevented normal growth in some instances and permitted the entrance of parasitic soil organisms to the cane plant.

The effects of nematode attacks on sugar cane were first investigated by Cobb (1906) and later by Lyon (1909-1919). Other members of the department have also studied the problem. Nematode damage to cane roots was reported to be moderate to severe in certain fields in 1916; the damage had increased in 1917. Damage to other crops was also reported. Nematode injury to sugar cane in more recent years has been considered of minor importance.

Barnum and Van Zwaluwenburg (1927) showed that growth failure was more severe on sugar cane when the *Pythium* fungus was in combination with *Isotomodes* than when either the fungus or *Isotomodes* was operating alone.

Rodents: Rat damage and economic losses therefrom have been of major significance to sugar and other agricultural industries. Various organisms causing a souring or rotting of the stalk often enter through the large wounds produced by the feeding of rats. Barnum (1931) published his studies on rat control that were carried out chiefly on Kauai.

Chemical Injuries:

Disease-like symptoms resulting from specific chemical injuries have always received the attention of the pathologists.

Fertilizer burn: Small quantities of hand-applied fertilizers frequently remain on individual leaves or become lodged in the central spindle of young plants. Shortly thereafter large irregular brownish-to-reddish areas become apparent on the foliage. Chlorotic streaks extending from the fertilizer injury toward the leaf tip often develop, resembling the leaf symptoms of chlorotic streak.

Iron sulphate spray: When iron sulphate spray is used for controlling ratoon chlorosis, it may cause a burning on the leaves in the form of small spots or large irregular dead patches. The injury results from the high acidity of the spray solution which is prepared from iron sulphate containing considerable free sulphuric acid.

Salt spray: Cane fields located near the ocean sometimes show a sudden browning of the leaves. The salt spray from the ocean is carried by the winds and is deposited on the cane leaves. Cane that is more or less continuously exposed to salt spray fails to make a normal growth. Salt spray injury has been reduced by establishing good windbreaks along the edges of fields.

Weed sprays: Chemical sprays for weed control have been used with marked success for many years. When weed sprays are applied, especially during windy weather, particles of the spray are carried for some distance, the result being that a definite leaf spotting develops. If a large quantity of the herbicide comes in contact with the plant, large irregular patches of dead-leaf or stalk tissue result.

Elemental Injuries:

As discussed elsewhere, the growth of a variety in a given locality depends largely on existing environmental conditions. Several elemental injuries have been studied and have been responsible for reduced sugar yields.

Fire burn: The excessive heat from cane and trash fires frequently scorches or burns the leaves of cane in nearby fields. The injury assumes the form of large, irregular patches of reddish-to-brownish areas on the leaves, the symptoms being very similar to those of certain infectious diseases.

Leaf burn: In 1909, Cobb described a disease known as wither tip. Later studies showed this condition to be the same as leaf burn which is recognized by a rapid wilting of large areas of leaf tissue, generally near the leaf tips; the affected tissue quickly dies and assumes a straw color. Leaf burn is due to excessive transpiration caused by winds, high temperatures, or both; the water is removed from the leaves at a greater rate than it is supplied from the stalks and roots of the plant. Certain varieties have proved much more sensitive (UD 1) to leaf burn than others (H 109

and D 1135). Leaf burn is more serious on rapidly growing canes than on canes making a slower growth. In 1929 Lee artifically produced leaf burn by subjecting potted plants to the breeze of a desk fan. Leaf burn in some localities has been severe and economic losses have occurred.

Lightning: This type of injury was first described by Cobb in 1907 under the name of top rot which at that time, as well as for some years to follow, was regarded as an infectious disease. Lyon and Carpenter and other staff members, in 1920, began to associate top rot with lightning injury, which later was proved to be the cause. The affected areas in the field are generally circular in shape and the leaves of the plants are yellowish-to-light-purple in color. Badly injured leaves hang down and are torn and shredded. Plants in the center of the area are often killed and the stalks soon develop a top rot due to the invasion of secondary organisms. The internodes of affected stalks show a marked shrinking followed by a general discoloration of the internal tissues.

Lightning striking in a cane field has uprooted cane plants. Soil particles coming from the disturbance have been found on nearby cane plants. Many cases of lightning injury have been recorded but in general economic losses have not been extensive.

Mechanical Injuries:

A certain amount of injury to the cane plant occurs during regular field operations; for example, roots and stalks have been cut with sharp edges of implements. "Pushing back" cane along ditches has caused considerable breakage to the stalks and damage to the root systems; if this practice is carried out following a rain or an irrigation little damage results.

A splitting of the internodes of cane varieties is an undesirable characteristic. An irregular supply of water causing a greater fluctuation in volume in the internal tissues than the rind, and the water-absorbing capacity of the stalks in the presence of high carbohydrates making the rind unable to resist the internal pressure, are two theories which have been advanced in explaining this condition. Organisms that cause a rotting and souring of the stalks have gained entrance to the plant through such injuries.

Other mechanical injuries of lesser importance have also been studied.

In the discussion on miscellaneous injuries an attempt has been made to list the more important ones in order to show that they have been directly or indirectly responsible for definite sugar losses, a total of which over many years would be of considerable importance.

Soil Biology

Considerable attention has been devoted by Martin and Carpenter to the principles of soil microbiology and how they might be applied to sugar-cane agriculture. The work in connection with this project has had to do with determining the numbers of aerobic bacteria and fungi occurring in plantation soils by the standard plate method.

The soil organisms, especially the bacteria, fungi, and actinomyces, are responsible for the decomposition of all waste organic plant residues which sooner or later become incorporated with and a part of the soil. In sugar-cane culture the

decomposition of cane trash, roots, and stubble by soil organisms play an extremely important part in maintaining normal fertility of soils.

The optimum carbon-nitrogen (C/N) ratio for plant growth on the mainland is reported to be around 10 or 11 : 1. If the ratio becomes wider than 11 : 1 then conditions are usually unfavorable for plant growth and nitrogen deficiency may result, but if the ratio is narrower than 11 : 1 then plant growth is stimulated, soil organisms become more numerous, and organic materials decompose more rapidly. The C/N ratio was determined on a number of plantation soils in 1938 and 1939 by staff members of the Chemistry Department and counts of the soil organisms were made by members of this department. During 1945 counts of soil organisms were made on a series of plantation soils supplied by Mr. Borden, who was studying soil fertility in relation to cane growth.

It has been shown that the microbiological population of the soil varies with temperature, acidity, soil moisture, amount of organic matter present, fertility, and the depth at which the soil samples were collected. The greater numbers of organisms were found to occur in the more fertile soils or where environmental conditions favor cane growth.

Sugar-Cane Root Studies

The research conducted on sugar-cane root diseases by staff members frequently required an understanding as to the behavior and development of normal roots in the soil. The experimental work carried out on this subject over a period of years has contributed considerable basic information relative to disease problems and to sugar-cane culture in general. A review of the investigations along these lines follows.

The normal distribution of cane roots of H 109, Lahaina, Striped Tip, and D 1135 in the soil was studied by Lee and Weller from 1925 to 1928. The results of these investigations were based on dry weights of roots collected at definite soil horizons. These experiments were carried out in the field and in large boxes with removable sides. Approximately 80 to 90 per cent of the roots were found in the upper 16 inches of soil and usually 70 per cent or more occurred in the upper eight inches. A correlation was found, "between heavy root weights and cane tonnage."

In conjunction with the distribution of cane roots in the soil, Lee and Weller also studied the relationship between seed-piece roots to shoot roots. The ratio between seed-piece roots and shoot roots during the first five months and the importance of shoot roots to the growth of the crop after the third month are brought out in the following table.

THE PERCENTAGES OF TOTAL ROOTS FOR EACH OF THE FIRST FIVE MONTHS

	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.
Seed-piece roots	97.3	22.7	1.2	0.4	0.2
Shoot roots	2.7	77.3	98.8	99.6	99.8

The development of seed-piece roots from root primordia was investigated by Weller in 1929. The objective in these studies was to determine the life cycle and active functioning periods of these roots and their relation to shoot-root development all of which has a direct bearing on sugar-cane growth. The average

number of possible roots per node from 50 three-eye cuttings of each of seven varieties was found to be as follows:

D 1135.....	122	P.O.J. 213...	45
H 109.....	116	Uba.....	38
Yellow Caledonia	114	P.O.J. 36*...	29
Lahaina.....	93		

Cuttings of these varieties were removed from the ground at the end of 5-, 10-,15-,20-, and 50-day periods, the number of roots that had developed were recorded and cut off, and the cuttings were replanted. Root development was less on the cuttings "left in the ground undisturbed for 50 days than for seed pieces disturbed at intervals of 5, 10, 15, and 25 days for the same period. A certain number of root primordia are held in reserve and develop only in case of need."

Subsequent to the foregoing root studies Weller in 1930 undertook to study the sugar-cane plant food requirements under field conditions through the analyses of root-pressure liquids. These liquids were collected by attaching rubber tubing to the cut surfaces of stalks of a stool of cane just above the ground and allowing the root pressure liquids to accumulate in flasks. The liquids were collected from different varieties growing under different conditions and analyzed for various constituents by members of the Chemistry Department. Larger quantities of liquids were collected and higher pressures were recorded during the night than during the day. In some instances "columns of mercury as high as 1400 mm. resulted."

When a tube was attached to the stump of one stalk of a stool solutions were readily taken in by the plant. This technique, "suction feeding," makes it possible to introduce various forms and amounts of materials into the plant and study their effects on cane growth; it also offers a method for transmitting infectious diseases to healthy plants. Attempts to transmit chlorotic streak and mosaic disease were made by Weller in 1932 but with negative results.

Penicillin Investigations

Penicillin, discovered in 1929 by Fleming, is relatively non-toxic to man but toxic to specific pathogenic bacteria at very low concentrations. Having these unique chemotherapeutic properties, it has been used with outstanding success for treating certain human diseases. Penicillin has been widely used in wartime surgery and in treating war casualties against septic poisoning.

The present supply of penicillin is derived from the green mold, *Penicillium notatum*, which is grown on, or in, a liquid medium for from five to nine days; during this time penicillin is produced by the mold and accumulates in the solution. The mold is separated from the solution by filtering and penicillin is extracted and purified from the filtrate. The yield of pure penicillin from liquid cultures is very low, approximately one ounce of penicillin being obtained from 125 gallons of solution.

At the request of Dr. Lyon, four strains of *P. notatum*, which had been used in the production of penicillin, were obtained in 1943 from two mainland laboratories—the object being to study their growth under local environmental conditions. One strain was a subculture of the original Fleming strain. Each strain

made an excellent growth on liquid and solid media; however, one strain was found to be superior to the others in the production of penicillin. For this reason it was used in all subsequent studies.

In the first studies, the extraction of penicillin from liquid solutions upon which the mold had been grown was undertaken by F. R. Van Brocklin (Chemistry Department) and Martin. For various reasons this work was abandoned.

Very little penicillin was available during 1943 for civilian use but the unconcentrated penicillin solutions were being used with great success in topical therapy. Coincident with, and independently of, the development of inoculated surgical gauze dressings on the mainland, Carpenter prepared penicillin dressings which were soon in demand by physicians. This Station was the first institution in the Territory to prepare penicillin solutions and surgical dressings for topical application and it was through Dr. Nils P. Larsen, Medical Advisor, H.S.P.A., that this service was extended to the plantation hospitals. Many local physicians soon became greatly interested in the project and wanted penicillin products for their clinical use. The distribution of all penicillin materials was under Dr. Larsen's supervision.

During 1944-45, the mold was grown on various culture media and in different types of containers in order to secure the maximum yield of penicillin as measured biologically by the Oxford ring test. Ways and means for concentrating the solutions by freezing and fractionating and for storing the products under refrigeration were investigated by Weller and Carpenter.

Many civilian and service physicians and technicians were given cultures of *P. notatum* and instructions for preparing penicillin products which have been made at sea and ashore. Dr. A. R. Agmar (Lieut. Comdr., M.C., U.S.N.R.) started to prepare penicillin materials at his dispensary according to the technique developed by this department; the results obtained from the cases treated were so dramatic that he was authorized by the Navy to produce penicillin solutions and gauze dressings on a large scale. He soon equipped a laboratory at Aiea for the production of these materials which were sent to forward areas by plane.

Both Carpenter and Weller devoted a great deal of their time to penicillin studies. The success of the project, the development and application of new ideas, and the addition of new sources of antibacterial substances in the field of "biotherapy" have been largely due to their investigations and interest in the problem.

It is felt that the humanitarian benefits derived from this project have been very much worthwhile not only to the plantations but to the community and service personnel as well. The speed with which many clinical cases recovered following treatment with the penicillin materials, as told by civilian and service physicians, has indeed been a great satisfaction to the men working on this project.

For a more detailed report on the experimental work conducted and the results obtained in these studies the reader is referred to an article in *The Hawaiian Planters' Record*, Vol. 49, No. 1, pp. 1-30, 1945, entitled "Studies with *Penicillium notatum* Westling in Hawaii" by Carpenter, Weller, and Martin.

Publications

Since the department was organized in 1905 a large amount of information relative to sugar-cane diseases and their control has been published. The early Bulletins and Circulars were published as the Pathological and Physiological

Series which later became known as the Botanical Series. In 1925 an unnumbered bulletin of the Experiment Station was published, entitled "Red-Stripe Disease Studies." Many publications appear in *The Hawaiian Planters' Record*, H.S.P.A. Proceedings, and a limited number in the Hawaiian Sugar Technologists' Proceedings.

All published and unpublished data of greatest importance on each disease were compiled by Martin and published in 1938 in book form. This book now serves as a guide for the identification of sugar-cane diseases in Hawaii. Each disease is described and illustrated. An extensive list of publications by the various staff members on sugar-cane diseases is included in the book under "Literature Cited."

In the foregoing pages the more important projects of the department have been briefly reviewed. However, it should be pointed out that an excellent picture of the problems of greatest economic importance and in their order of time, as investigated by staff members, is to be had by referring to the publications of the department.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16, 1948, TO AUGUST 16, 1948

Date	Per Pound	Per Ton
March 16, 1948—March 18, 1948	5.30¢	$106.00
March 19, 1948—March 28, 1948	5.40	108.00
March 29, 1948—March 31, 1948	5.45	109.00
April 1, 1948—April 19, 1948	5.40	108.00
April 20, 1948—April 28, 1948	5.35	107.00
April 29, 1948—May 6, 1948	5.20	104.00
May 7, 1948—May 9, 1948	5.15	103.00
May 10, 1948—May 19, 1948	5.10	102.00
May 20, 1948—May 26, 1948	5.15	103.00
May 27, 1948—June 3, 1948	5.25	105.00
June 4, 1948—June 8, 1948	5.288	105.76
June 9, 1948—June 14, 1948	5.20	104.00
June 15, 1948—June 16, 1948	5.30	106.00
June 17, 1948—June 21, 1948	5.35	107.00
June 22, 1948	5.40	108.00
June 23, 1948—June 28, 1948	5.45	109.00
June 29, 1948—July 7, 1948	5.60	112.00
July 8, 1948	5.65	113.00
July 9, 1948—July 12, 1948	5.75	115.00
July 13, 1948—July 21, 1948	5.70	114.00
July 22, 1948—July 28, 1948	5.75	115.00
July 29, 1948—August 1, 1948	5.78	115.60
August 2, 1948—August 16, 1948	5.80	116.00

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